Potentiality analysis for urban planning

Rudi Stouffs *1
Patrick JANSSEN *2
Ye ZHANG *3
(*1 National University of Singapore, Singapore, Associate Professor, stouffs@nus.edu.sg)
(*2 National University of Singapore, Singapore, Associate Professor, patrick@janssen.name)
(*3 National University of Singapore, Singapore, Assistant Professor, akizy@nus.edu.sg)

Abstract. We report on a methodology for computational analysis of the potential for the development of urban nodes within an industrial estate in order to transform the estate from an almost mono-functional, segregated and fragmented, highly polluted industrial area into a major catchment area for future population growth that integrates clean(ed) industrial plants with green lungs, attractive housing and vibrant urbanity for up to one million people to live, work and play by 2050. We adopt a location choice approach, considering land availability, accessibility to transit, presence of parks and traffic noise exposure as influencing factors. Our selection is partially driven by data availability and partially by existing scenario planning processes that we aim to support by generating alternative scenarios or providing arguments in support of such scenarios. Land availability is mainly affected by land leases and safety buffers. We adopt a sigmoid curve to normalise land lease end dates between 0 and 1, apply this curve to both land leases and safety buffers, and consider the minimum of both as land availability analysis value. For accessibility to transit, we consider a proximity analysis based on walkable distances to different modes of public transportation. Distances are normalized and additionally weighted by transit mode. For parks, we consider both the accessibility and the area of green spaces in the analysis. We discount waterbodies from the analysis as few are accessible or are otherwise part of a park or green space. Similarly, we discount the presence of industry because this is already taken into account indirectly via the land availability analysis and the final cumulative, aggregate urban potential analysis. We do take into account exposure to traffic noise for the main expressway passing through the estate area. The final analysis outcome is a weighted aggregation of these four analyses and we consider the weights as parameters for the urban planner to play with. A normalized accumulation of analysis values illustrates urban potential over the area of a neighbourhood or catchment area. The actual selection of urban nodes remains as a task for the urban planners, with the individual, aggregate and cumulative analyses serving both the selection and their argumentation.

Keywords. Urban Planning, Computational Analysis, Location Choice, Urban Potential

Introduction

Long-term urban planning is eminently difficult and complex. In Singapore, urban planning is a highly centralised government function, with the Urban Redevelopment Authority (URA) being the designated national land use planning authority [1]. In collaboration with relevant government agencies and public consultation, URA develops a Concept Plan covering strategic land use and transportation and providing broad directions to guide Singapore's physical development over the next 40 to 50 years [2]. This Concept Plan is reviewed every 10 years; the latest review was carried out in 2011-2013 and led to the release of the Land Use Plan 2030 by the Ministry of National Development (MND). The latter is a conceptual plan outlining strategies to provide the physical capacity to sustain a high quality living environment for a projected population range of 6.5 to 6.9 million by 2030 [3] (which currently stands at 5.61 million as of June 2017 [4]). The broad long-term strategies of the Concept Plan are also translated into the Master Plan, a statutory land-use plan that specifies permissible land use and densities, and guides the physical development of Singapore over the next 10 to 15 years [1]. This Master Plan is reviewed about every five years; the latest version dates from 2014 (figure 1).

The Concept Plan ensures that there is sufficient land to support long-term population and economic growth while maintaining a good living environment, balancing housing, industry, commerce, parks, transport, defence and community facilities [1]. Strategies to sustain a high-quality living environment include: providing good affordable homes with a full range of amenities; integrating greenery into the living environment; providing greater mobility with enhanced transport connectivity; sustaining a vibrant economy with good jobs; and ensuring room for growth and a good living environment in future [2]. One possible area for future growth is the Jurong Industrial Estate (JIE), a mono-functional industrial estate incorporating about 4000ha in the west of Singapore. While future developments of public transportation already guarantee improved accessibility to the JIE, the current Master Plan assigns almost exclusively industrial land use (figure 2).

JIE is managed by JTC Corporation, Singapore's largest developer of industrial lands. With collaboration from JTC's Urban Planning Department, we adopt JIE as a case study for an urban potentiality analysis with the aim to generate planning scenarios and their argumentation. Our assumption for this case study is to convert this almost mono-functional, segregated and fragmented, highly polluted industrial area by 2050 into a major catchment area for future population growth that integrates clean(ed) industrial plants with green lungs, attractive housing and vibrant urbanity for up to one million people to live, work and play.

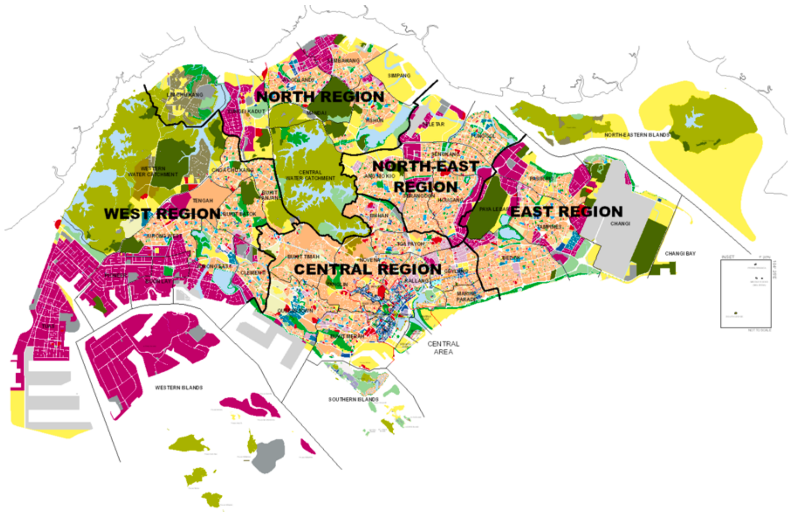

Figure 1. The URA (Urban Redevelopment Authority) Master Plan 2014.

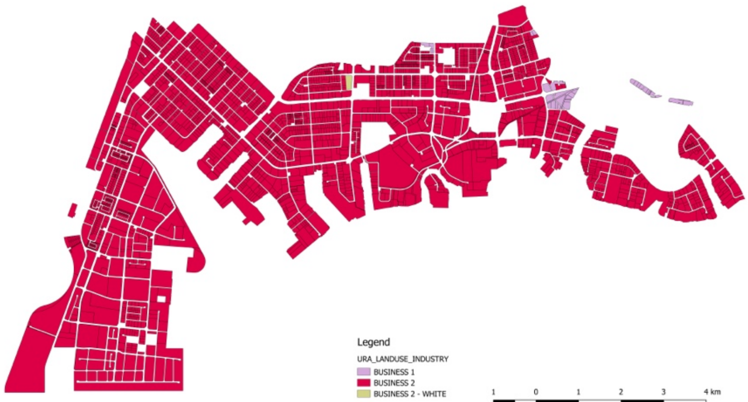

Figure 2. The Jurong Industrial Estate in the west of Singapore. Land use categories are taken from the URA Master Plan 2014.

JIE is currently served by one expressway and one Mass Rapid Transit (MRT) line, both running east to west through JIE and linking JIE with Singapore’s Central Business District and beyond, as well as one expressway and one MRT line heading north. In addition, a second cross-island MRT line serving JIE is in the planning phase and scheduled to open in 2030 [5], with a regional line linking a smaller area of JIE with existing developments north of the industrial estate scheduled to open in 2025 [6]. The entire estate is mainly flat with only one hill of significance, the Jurong Hill, which, next to a recreational park, also sports the Jurong Bird Park, Asia’s largest avian wildlife park and the only tourist attraction within JIE. However, the bird park is slated to move to the Mandai Project development elsewhere in Singapore.

Obviously, time-dependent issues exacerbate the development of planning scenarios. Land lease ends of current industrial occupants, health and safety buffers relating to existing industrial plants, planned land reclamation and rapid transit developments are still rather straightforward to address as these are well known to the planners. However, other future changes may be largely unknown or at best undecided, including additional land reclamation and further transport network developments, such as the bus network responding to changes in land use, demographics, density, etc. Ideally, scenarios should also take into account issues of liveability and vibrancy, including presence of parks, industry, road traffic exposure, various interdependencies between these and other factors, etc.

The difficulty and complexity of urban planning for the longer-term is not a hindrance to the planning process per se, but does effect the efficiency and productivity of the planning process and the ability to conceive and consider sufficient variants in order to gain confidence in the ultimate value of the urban plans and scenarios developed. It is in this context that we are supporting JTC’s Urban Planning Department to computationally generate planning scenarios for the conversion of JIE into a mixed-use urban environment. In this paper, we report on the methodology we have developed to identify the potential for urban nodes within JIE as well as related analyses. Urban nodes are here considered as locations for the development of high-density urban neighbourhoods that are attractive for people to live, work and play.

1. METHODOLOGY

At the large scale, the focus is on identifying the potential for urban nodes within JIE. This potential is influenced by a number of aspects relating to plots and their environment, such as plots' lease ends, health and safety buffers relating to other plots or transport lines that impact the plot in question, accessibility to public transportation, presence of green spaces and waterbodies, exposure to traffic noise, and proximity to industry of various categories. The main approach is a grid-based analysis of the area using GIS data and software (QGIS) over a range of criteria and aggregating these analyses in a hierarchical manner, specifying weights at each level where these weights can be identified as parameters to be adjusted by the planners.

For the urban potentiality analysis, we use an analysis grid rather than plots, as plots may be combined or divided, local (Cat. 5) and primary (Cat. 4) access roads may be added, retraced or even removed, canals may be dug, land set aside for future green or land may be reclaimed from the sea or other waterbodies. We have settled on a 30m x 30m grid, which is small enough for detailed analyses, at the overall scale of JIE or, approximately, even at the level of a single plot or plots, but not too small so as to make the computation process not too heavy. It is also the same resolution as, among others, Landsat 7 satellite images and the United States Geological Survey (USGS) ground cover map. We have adjusted the analysis grid by adding any anticipated reclaimed lands, subtracting expressways (Cat. 1) and major (Cat. 2) and minor (Cat. 3) arterial roads, and subtracting non-industrial land use. At the north-eastern border of JIE are some areas already classified as residential, commercial, or other non-industrial use, and developed as such. As a result of these adjustments, not all grid cells have the same shape or size. However, this does not significantly impact the analysis process.

We are basically adopting a location choice approach [7], considering 1) land availability, 2) accessibility to transit, 3) presence of parks, 4) presence of industry and 5) traffic noise exposure. Though other relevant factors can be identified or considered, our selection has been mainly driven by data availability. Nevertheless, we acknowledge the limitations of our selection and we have been investigating other factors for future inclusion, such as diversity land use mix and regional accessibility. However, more important than being complete in our analysis is to support JTC's urban planners in developing acceptable scenarios or providing arguments to have these scenarios accepted by higher management. As such, we need to balance research and practice, informing our approach from research but adhering to a practical aim.

1.1. Land availability

Land availability is affected by land leases, appropriation of land for other than industrial purposes, land reclamation and health and safety buffers. In Singapore's latest Master Plan, dating from 2014, most of the land within JIE is assigned as property type Business 2 (B2) for general (as well as light) industrial use (figure 2). A small portion of JIE is assigned different property types, including residential, commercial, park, waterbody, civic & community institution, utility, reserve and special use. For the sake of the case study, we accept all other property types as fixed and limit the generation of planning scenarios to land currently assigned as B2 (and B1), as this is the land currently managed by JTC, while considering adjacency relationships to other land with different property types.

As industrial use is acknowledged to cause noise and smell nuisance, B2 assumes a nuisance buffer of 100m, that is, no residential (or similar) developments can take place within a 100m distance from a B2 property type. This condition is commonly resolved by separating both uses by a major or minor arterial road that is sufficiently wide. In addition, industries may be required to implement nuisance controls to ensure the 100m buffer is sufficient. Next to nuisance buffers, specific industries may require health and safety buffers to be imposed. Health buffers are mainly related to industries with exhaust fumes from incineration or other industrial processes and result in height restrictions to ensure no developments exceed the height of the exhaust within the stated buffer. Safety buffers, on the other hand, relate to the risk of hazards or incidents that may affect a larger area, such as explosions or the accidental release of toxic chemicals. Safety buffers will be imposed based on risk and impact assessment, but may be updated after a specific incident demonstrated the need for a larger buffer. In principle, safety buffers must be entirely contained within the plot assigned to the industry, though for historical reasons, current safety buffers may exceed the plot boundaries and will, therefore, affect adjacent plots. Safety buffers can be related to lease ends, because the buffer would disappear once the industry has ended its operations or has moved elsewhere.

Safety buffers are also imposed for the transportation of fuels and other combustible or toxic chemicals. Such safety buffers may extend up to 800m on either side of the road and have a massive impact on the ability to develop urban nodes within JIE. Of course, safety buffers related to transport lines are fewer as multiple industries can be required to adopt the same transport lines and may be easier to adjust by conceiving and developing new transport lines.

Finally, land reclamation is treated similar to land leases with the date of completion of the reclamation activity as the lease end date. The current property type, before land reclamation is completed, is considered as Waterbody. Future appropriation of land for other than industrial purposes, e.g., future green or waterbodies that are being conceived as part of the scenario development, can be treated oppositely, with a start date for the appropriation and a future property type, after the appropriation. In the analysis of urban potentiality, however, we consider these lands as not available.

In principle, land availability is measured at a point in time. However, for the sake of assessing urban potentiality, we are adopting an analysis over time, using a sigmoid function to transform a point in time into a value between 0 and 1, where 0 means no availability at all and 1 means immediate availability. Because 2050 is considered as the target date, we consider 2050 as the inflection point (figure 3) and 2010-2090 as the primary range (all current lease ends predate 2070) for the sigmoid curve. When applied to lease ends, any lease ending before 2050 will result in a value greater than 0.5, while any lease ending after 2050 will result in a value less than 0.5. We apply this analysis to lease ends as well as to safety buffers, acknowledging that safety buffers relating to plots are also bound by these plots' lease ends. Overall, land availability is considered impacted by lease ends and safety buffers ending in time. The final value for land availability is determined as the minimum of the values of either analysis, as both should be read as restricting availability.

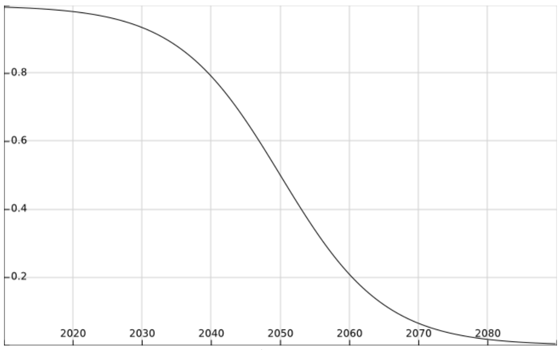

Figure 3. The sigmoid function $y = 1 - 1/(1 + e^{\frac{2050-x}{7.5}})$ transforming points in time into the range 0 to 1 [image source: fooplot.com].

1.2. Accessibility to transit

Transit planners generally consider a walkable distance of 400m. However, studies on average walking distances in different cities have resulted in varying averages and correlations between walking distances (to bus stops) and the percentage of people (transit users) walking at least this distance. A survey study conducted in Singapore revealed an average walking distance of 187m to bus stops, 226m to Light Rail Transit (LRT) stations and 608m to MRT stations [8]. While these distances are measured over actual walkways, in the context of future urban developments, we must instead use straight-line distances and reduce these averages accordingly. We adopt the assumption that in a porous area or over a well-connected grid, the straight-line distance may be about 80% of the actual walking distance. Furthermore, we omit the distinction between bus stops and LRT stations and use curve-fitting to deduce a function that can transform distances into accessibility values between 0 and 1. Simplifying the exponent values in the functions, we arrived at a general function of *probability* = 1/(1 + (*distance*/*average*)^3) with an average walking distance for bus stops of 150m and for MRT stations of 450m (figure 4).

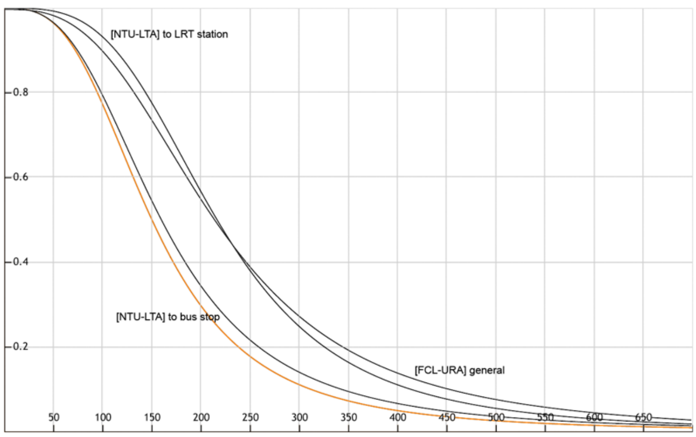

Figure 4. A comparison of the adopted function $y = 1/(1 + \left(\frac{x}{150}\right)^3)$ (highlighted in orange) transforming distances to bus stops into probabilities within the range 0 to 1, with fitted curves derived from two Singapore studies: an NTU-LTA study [8] and an FCL-URA study [9]. Note that the latter is a general walkability study conducted in the CBD [image components source: fooplot.com].

Overall, accessibility to transit is a combination of accessibility to pick-up/drop-off points for different modes of public transportation. Here, we distinguish between trunk buses and feeder buses and acknowledge a preference of MRT over trunk and feeder buses, beyond the distinction in average walking distance. Therefore, we are adopting weights of 1, 0.75 and 0.5, for MRT, trunk buses and feeder buses respectively, with the final value for accessibility to transit as the maximum of all three values when multiplied by the respective weights. We acknowledge that these weights may seem rather arbitrary, however, we consider them as mere parameters that could be adjusted by the planner in an exploratory manner. In addition, we try to take into account future MRT lines, even if the location of the lines and stations is not yet known. Making appropriate assumptions, we distinguish projected MRT llines from existing lines and take into account the projected development timeframe and reduce the value at the ration of the number of years until operation over the number of years until about 2080 (considering 2050 as the half-way point between now and approximately 2080).

1.3. Presence of green spaces (and waterbodies)

As is common in a location choice approach [7], we consider both the accessibility and the area of green spaces in the analysis. Walkable distance to parks generally depends on quality and amenities. As JIE currently contains very few green spaces and any existing parks will likely be redeveloped, we consider a conservative measure of accessibility by adopting the same 150m radius for (projected) green spaces as we have done for bus stops.

For areal measurement, we consider a well-connected neighbourhood as the basis with an 800m walking distance or a 640m radius, and measure the total green area within this neighbourhood. Once again, we adopt a sigmoid function to normalise the area within the range of 0 and 1. With a few exceptions, most large recreational parks in Singapore have an area of around $0.5km^2$ to $0.6km^2$. Tentative plans for the development of new or expanded green spaces within JIE corroborate this result. As such, we have selected $0.25km^2$ as the inflection point of the sigmoid curve. Note that the total area of a neighbourhood with 640m radius is almost $1.29km^2$.

Projected green spaces may include both recreational parks and stretches of greenery, the latter lining up selected coastlines, river banks, existing or projected canals, and minor arterial roads. For this reason, we take both parks and greenery into account with respect to accessibility, while only the former contribute to the areal analysis. As such, when combining both analyses under a weighted sum, the greenery will play a minor role with respect to the parks. As a default, we consider a 50/50 weighing of accessibility and area of green spaces, though these weights can be easily adapted by the planners.

While the same analysis may apply to waterbodies, very few waterbodies in JIE are accessible to the public. Most of the coastline is not and while some parts may be considered to be made accessible and be lined with greenery, most of the coastline is anticipated to remain industrial. Rivers and canals may similarly be projected to become accessible and be lined with greenery, while other waterbodies within or near JIE already form part of a park or are projected to be integrated into a park. As greenery is already considered as part of the green spaces analysis, we omit a similar analysis of accessible waterbodies. Only for other kinds of analysis processes, such as industrial land sourcing, do we consider proximity to the industrial coastline as a potentially contributing factor.

1.4. Presence of industry

The presence of industry is commonly considered to negatively impact residential location choice [7]. Next to the share of industrial land use within the neighbourhood, the proximity of industry may also be considered in this assessment. It is well known in Singapore that people prefer not to live within visual proximity of industrial buildings. While the visual recognition of their industrial character and their aesthetics may play a role, and thus may allow for some alleviation through design, it remains important to consider their presence as an influencing factor. Considering that a 100m nuisance buffer is commonly established by the dividing presence of an arterial road, we may consider a distance of at least 300m through the adoption of a sigmoid function with inflection point at 150m. In addition, we can apply the same areal analysis for industry as for green spaces, obviously with an opposite impact.

When focusing on identifying potential urban nodes, we actually omit the presence of industry and refer instead to the land availability analysis. While the presence of industry with respect to land availability does not impact the surrounding area, except in the case of safety buffers, the cumulative, aggregate urban potential over a “neighbourhood” with 640m radius (see section 1.6) does expand the impact of present industry over its surrounding area.

1.5. Exposure to traffic noise

Another negative impact is exposure to traffic noise. As it is very hard to anticipate the impact on traffic volume as a result of urban developments in JIE, we are mainly concerned about the expressway running through the estate. Lau et al. [10] report on a road traffic noise study conducted for the same expressway though at a point outside of JIE. Measuring hourly traffic flows, % of heavy vehicles and mean traffic speed from 6:00 until 24:00, they used the commonly adopted CRTN method to predict an L10(18h) level of 73.5

dBA. In addition, they measured the road traffic noise level at 15m from the nearside edge of the road and 1.2m above the ground, resulting in a L10(18h) level of 70.0 dBA. Additionally, we should note that at the measuring location, the expressway is an 8-lane city-level highway with heavy traffic flows, including commuter traffic (% of heavy vehicles measured reached a highest value of 24.6 (14:00) and a lowest value of 13.3% (23:00)). Instead, throughout JIE, the expressway is mostly a 6-lane highway either at ground level or at overpass level, with much fewer commuter traffic and, thus, a higher percentage of heavy vehicles. As such, we consider the measured value of 70 dBA as guiding. Using a predictive tool [11], we approximated the expected distance for a reduced noise level of 50 dBA at about 340m. Considering that further reductions of the noise level require ever larger distances, we selected 340m as the half-way point ($y = 0.5$) and a low exponent of 1.1 (figure 5).

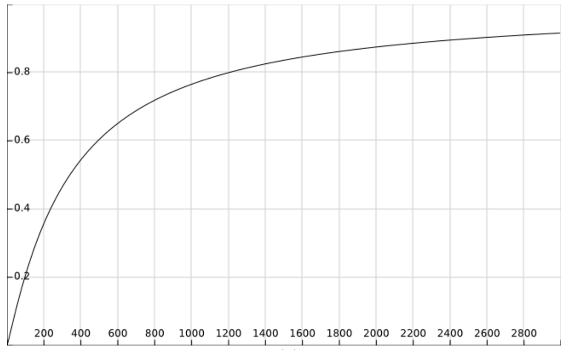

Figure 5. The adopted function $y = 1 - 1/(1 + \left(\frac{x}{340}\right)^{1.1})$ transforming distances to the expressway within the range 0 to 1, guided by measured and predicted noise levels [image source: fooplot.com].

1.6. Aggregate analysis

To determine urban potential we first consider the aggregation of four of the five aspects considered above: land availability, accessibility to transit, presence of green spaces and exposure to traffic noise. The aggregation is achieved by summing the weighted outcomes of these four analyses (figure 6, figure 7). The actual weights should be considered as parameters for the planner to play with.

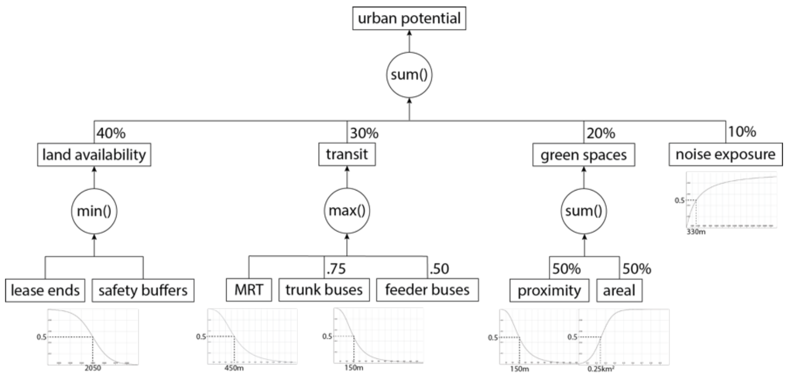

Figure 6. The aggregate analysis for urban potential. The respective weights should be considered as parameters for the planner to play with.

Urban nodes necessarily need a critical mass. For this reason, we additionally compute for each grid cell a normalised cumulative urban potential over a “neighbourhood” with 640m radius about the grid cell. This accumulation will favour areas with consistently high values, rather than peak values surrounded by much lower urban potential. In order to normalise the result, we can divide the cumulative urban potential value by the summed area of all grid cells within the neighbourhood. Unfortunately, this favours smaller boundary areas which may include a relatively higher number of near-peak values. For this reason, we consider dividing the cumulative urban potential value by the weighted sum of, on the one hand, the actual neighbourhood area as the summed area of all grid cells and, on the other hand, the maximum neighbourhood area, $\pi * 640^2$. Using weights of 2/3 and 1/3, respectively, presented us with a more balanced result.

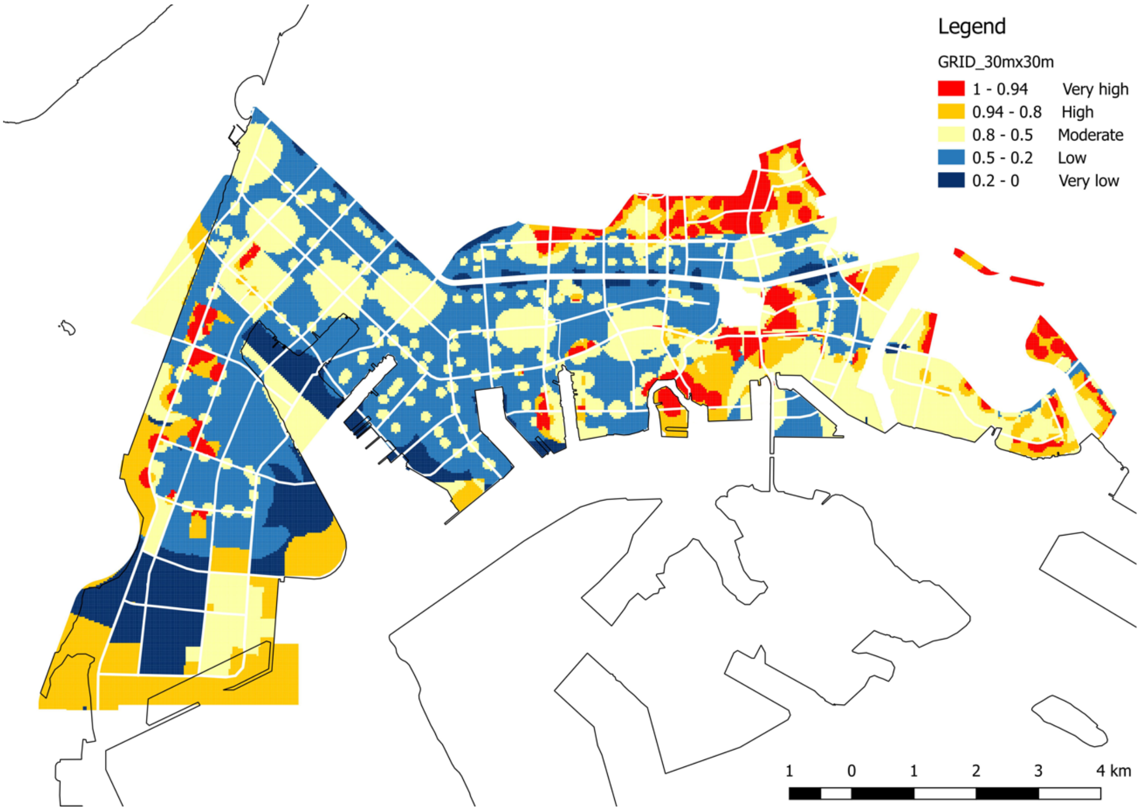

Figure 7. The result from the aggregate analysis for urban potential.

2. DISCUSSION

From the cumulative urban potential, urban nodes could be selected automatically as centred on cells with the highest cumulative urban potential values. The size of the urban node or growth area could subsequently be deduced from the aggregate urban potential through sampling. However, as urban nodes should be some minimum distance apart, selecting urban nodes would be an iterative process of selecting the highest cumulative value, determining, the radius of the urban node from the landscape of aggregate values, then excluding a buffer area (with a minimum radius of twice the radius of the urban node), before selecting another node, etc. However, we argue that this selection process should not be automated and should, instead, be left to the urban planners, based on both the aggregate and cumulative urban potential, any other information generated from the methodology here described and, of course, other information the urban planners may deem relevant or appropriate. In this light, the automated quantitative approach can be used as an exploratory means to identify urban potential and understand the impact of the different aspects with respect to this potential, and as a providing some objective underpinning that can serve as arguments to support the decision-making process on the location of urban nodes.

Once the selection of urban nodes has been made, this selection, in turn, serves to guide the land use and density planning that will serve to influence the future Master Plan. The computational support to this planning process will follow a similar approach of location choice and aggregate analysis, although the analyses will be time dependent and differ both in the analyses, including urban catchment, and the aggregation.

3. CONCLUSION

We have presented a methodology for computational analysis of the potential for the development of urban nodes within an industrial estate in order to transform the estate into a major catchment area for future population growth. We adopted a location choice approach, considering land availability, accessibility to transit, presence of parks, presence of industry and traffic noise exposure as influencing factors. The aggregation of the analyses is considered as a weighted sum, with the potential for the urban planners adopting the methodology to play with the weights. The selection of urban nodes proceeds from a normalised cumulative urban potential calculated over a neighbourhood area.

Acknowledgments
This work received funding support from NUS-JTC i^3 Centre. We would like to thank the Urban Planning Department of JTC, under the Deputy Directorship of Aloysius Iwan Handono, for their invaluable support.

References

[1] Shereen Tay. Urban planning framework in Singapore. *SingaporeInfopedia*, National Library Board, 2008. http://eresources.nlb.gov.sg/infopedia/articles/SIP_1565_2009-09-09.html. Last accessed: 5 February 2018.

[2] Urban Redevelopment Authority. About the Concept Plan. https://www.ura.gov.sg/Corporate/Planning/Concept-Plan/About-Concept-Plan. Last accessed: 27 February 2018.

[3] Urban Redevelopment Authority. Concept Plan 2011 and MND Land Use Plan. https://www.ura.gov.sg/Corporate/Planning/Concept-Plan/Land-Use-Plan. Last accessed: 27 February 2018.

[4] Department of Statistics, Ministry of Trade & Industry. Population Trends, 2017. http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/population_and_population_structure/population2017.pdf. Last accessed: 5 February 2018.

[5] Land Transport Authority. Cross Island Line. https://www.lta.gov.sg/content/ltaweb/en/public-transport/projects/cross-island-line.html. Last accessed: 27 February 2018.

[6] Land Transport Authority. Jurong Region Line. https://www.lta.gov.sg/content/ltaweb/en/public-transport/projects/jurong-region-line.html. Last accessed: 27 February 2018.

[7] Patrick Schirmer, Michael van Eggermond, Kay Axhausen. The role of location in residential location choice models: a review of literature. *The Journal of Transport and Land Use* 7(2)(2014), 3-21.

[8] Piotr Olszewski, Sony Sulaksono Wibowo. Using Equivalent Walking Distance to Assess Pedestrian Accessibility to Transit Stations in Singapore. *Transportation Research Record: Journal of the Transportation Research Board* 1927 (2005), 38-45.

[9] Alex Erath, Michael van Eggermond, Sergio Ordonez, Kay Axhausen. Modelling for Walkability: understanding pedestrians' preferences in Singapore. In *Proceedings of the 14th International Conference on Travel Behavior Research*, Windsor, UK, 19-23 July 2015.

[10] Siu Yu Stephen Lau, Ji Zhang, Siu-Kit Lau, Hongzhan Lai. A Comparative Study of Road Traffic Noise based on Measurement, Prediction and Simulation according to the CRTN Method in Singapore. In *Proceedings of the 9th Cross-Strait Acoustic Conference*, Macau, China, 11-12 August 2016.

[11] Calculation of road traffic noise according to the 2002 version of the Dutch calculation method. https://rigolett.home.xs4all.nl/ENGELS/vlgcalc.htm. Last accessed: 26 January 2018.