EVALUATING THE ACCESSIBILITY OF GREEN NETWORKS: A CASE STUDY ON NEW CITIES IN SEOUL METROPOLITAN AREA (1065)

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Abstract. Demand for urban green networks has increased and the accessibility have become major concerns, but related discussions have so far been restricted only to green spaces. Through a case study on second- and third-phase new cities in Seoul metropolitan area, this study suggests new indicators to evaluate the synergy between road and green networks in urban areas. Applying the suggested method on the new cities of Dongtan, Wirye, Wangsuk and Gyosan, this study demonstrates how the indicators explain the spatial structure of the green networks and verifies the structural characteristics of each new city. One of the main conclusions are that third-phase new cities' green networks have higher integration and lower control. Implications for the difference between cities and phases are further discussed.

Keywords: Green Network, Spatial Accessibility, Space Syntax, Korean New City, Synergy

1. Introduction

Recently, the demand for open spaces near residential areas has rapidly increased in South Korea due to the experience of COVID-19. Concerns about densely populated urban hotspots have led to a higher appeal for open spaces located in less densely populated areas and outdoors. Kim (2021) compared the movement and stay patterns of citizens before and after the COVID-19 outbreak based on telecommunication data of Seoul citizens. The study revealed an increase in the usage and stay time of parks within the citizens' walking distance after the occurrence of COVID-19. In addition, a survey on citizen satisfaction and improvement demands regarding parks revealed that the highest demand was for 'strengthening the residential area planning regarding green space'. Along with this change in citizen awareness, keywords such as walking, greenery, and neighborhoods have emerged in urban design in Korea. This trend is also rising worldwide, with the 15-minute neighborhood plan in Paris being a prominent example. This plan, which focuses on environmental preservation and human-centered urban design, has had a significant global impact on urban spaces. There have been cases in the Seoul metropolitan area where attempts were made to implement a 30-minute neighborhood plan.

New cities, especially those in the Seoul metropolitan area, serve as the most accessible subjects for understanding the flow of Korean urban design. The new cities particularly reflect the trend of urban design for each period very well. Korean new cities refer to the planned development areas created according to ‘the Land Development Acceleration Act’. In the late 1980s, in order to alleviate the shortage of land supply within the Seoul metropolitan area, five first-phase new cities were constructed. Then, in the 2000s, 12 second-phase new cities were built, followed by ongoing construction of around ten third-phase new cities. The number of third-phase new cities varies somewhat depending on the definition and classification, so it is expressed as "around ten." According to Oh and Lim (2014), the construction of the first-phase new cities was hastily pursued around the 1988 Seoul Olympics, resulting in various side effects. The construction beyond the development restriction areas increased unnecessary travel distances and the large-scale construction projects led to material shortages and price increases. Furthermore, there was criticism that the focus on land supply resulted in a decline in the self-sustainability of cities and increased transportation costs to the Seoul metropolitan area. As a result, from the 2000s, the urban design approach of "pre-planning followed by development" emerged to minimize the side effects of large-scale development.

The second-phase new cities, constructed under the new design approach, gradually addressed the issues that arose in the first-phase new cities. According to the Specialization Plan and Design Guidelines for the High-Quality Development of Second-Phase New Cities (Korea Land and Housing Corporation, 2009), unlike the first-phase new cities, which mostly became bed-towns, the second-phase new cities were planned, designed, and constructed to encompass urban culture, nature, and industrial revitalization for self-sufficiency. The second-phase new cities actively utilised natural resources with various mountainous areas and rivers being reborn as parks integrated into residents' daily lives. From the second-phase new cities onwards, green spaces began to receive significant attention as an essential element of urban design. This trend was further strengthened in the third-phase new cities, with an increase in the overall proportion of green spaces and efforts to activate green networks within.

2. Literature Review

2.1. New City and Green Spaces

Various studies have been conducted on green spaces in the fields of urban design. New cities, in particular, have been extensively utilised as subjects for green space studies, showcasing distinct design principles from different time stamps. This has allowed for a direct evaluation of the results of urban design, including the planning process and public reactions. Consequently, many studies related to green spaces in new cities have approached the subject from the perspectives of residents' satisfaction and accessibility. Kim Y. and J. Kim

(2011) conducted a macro-level analysis on the impact of green spaces in the metropolitan area on residents' quality of life. Um and Lee (2008) established an accessibility model based on residents' utilisation rates of green space systems in small-scale towns in the metropolitan area, deriving improvement strategies for planning. Lim and Kim (2011) aimed to identify the connection between green spaces in new cities and their surrounding areas, emphasizing the improvement of ecological connectivity within green networks.

Research on the usage patterns of green spaces has also been actively pursued. Lee (2011) discovered that service quality and accessibility are crucial for the users. Additionally, Yeom and Park (2011) found that efficient access and connectivity systems for parks can enhance overall satisfaction for green spaces. Furthermore, Kim (2010) revealed that linear urban elements are frequently embraced in the design of green networks in new to activate such networks. As a result, research on green spaces in Korea has extensively involved surveys targeting users and studies focusing on the forms of green spaces. This has provided insights into the types of green spaces preferred by citizens and how to design them to enhance convenience. Examining the history of Korean new cities, we can observe that the green networks has continuously evolved based on these research findings. In particular, designs based on natural elements such as rivers and mountains, as well as linear parks, have been actively implemented.

In this study, we aim to go beyond the insights obtained from previous research and evaluate the placement of green spaces from a perspective of the overall urban structure. While previous studies have focused solely on green spaces, our study intends to assess the accessibility of green spaces within the city, considering not only the green areas but also the riverbanks, pedestrian paths, walkways, and all the routes and squares frequented by citizens. We consider the road and green networks as key elements in urban design, and based on their relationship, we aim to evaluate the accessibility of green spaces. Kim and Choi (2013) explain this concept as "synergy”. They argue that to evaluate the quality of linear systems, a concept beyond the traditional point-based assessment is required. The notion of a good network goes beyond the distribution of individual facilities and implies the existence of an overall linear connectivity that is intricately linked to residents' daily activities, movement patterns, and the essential functions of the city. In other words, a high level of synergy implies that green spaces are networked and have a close relationship with the flow of the city itself. Therefore, in this study, we aim to evaluate the connectivity and excellence of green spaces in new cities based on the concept of synergy.

2.2. Space Syntax Theory

Among various methods that analyse the form and scale of networks, the most representative one is space syntax. Space syntax is a set of analysis tools or theories that analyse spatial structures, particularly as networks. It was invented and developed by Hillier and Hanson in the late 1970s, and has since been widely used as a useful tool. Space syntax encompasses the domains of accessibility, which analyses linear networks, and visibility, which analyses the areal space. Accessibility is mainly used to analyse road and green networks within cities, while visibility analysis is primarily applied to a single street or indoor spaces. In this study, we use the accessibility analysis to examine the relationship between road and green networks.

Space syntax has been used to analyse accessibility in various aspects of urban spaces, both macro and micro. Yıldırım and Celik (2023) conducted accessibility analysis and on-site behavioral observations to analyse the pedestrian environment of Istanbul's central marketplace. They investigated how the results of space syntax indicators associates with people's actual behavioral patterns. El-Darwish (2022) used accessibility analysis to investigate the pedestrian environment within a university campus in Egypt. By comparing the current pedestrian network with potential revised network which might result from changes in building entrances and the utilisation of open spaces, they provided quantitative validity for improving the pedestrian environment within the campus. Joo and Kwon (2022) used space syntax to examine the changes in road structure resulting from the introduction of super-grids in Seoul's central district. They analysed macro-level traffic flow along with spatial changes in small-scale living areas. Additionally, Kim and Yang (2021) and Park (2021) analysed changes in gentrification areas of Seoul from the perspectives of commercial activation and urban regeneration, respectively. They empirically analysed which types of shops are likely to be established based on the differences in road accessibility. As such, space syntax enables network analysis of urban systems and provides meaningful insights when combined with various elements of the city.

In Space syntax, accessibility is primarily interpreted from an angular perspective. The angular perspective values how many turns pedestrians experience while using a network. In other words, accessibility evaluates paths with straight and intuitive understandability as more accessible, even if they are slightly longer in distance compared to paths with complex routing but shorter travel distance. Turner (2001) and Hillier and Iida (2005) developed space syntax based on the concept of accessibility to represent and analyse urban structures as axial lines. Initially, the methodology used axial lines for analysis, but the subsequent development of segment lines enhanced the explanatory power of accessibility analysis. Unlike axial lines, segment lines break at points where intersections occur between axial lines, which allows recognizing and analysing a long road as multiple shorter segments. This difference enables the analysis and recognition of road segments that occur at multiple intersections in a city as separate elements, enhancing the precision.

When people use roads, they consider not only the topological perspective but also various factors including distance. Researchers have continuously improved the methodology to reflect these pedestrian characteristics. Particularly, Hillier (2007) and Al-Sayed (2014) introduced a technique in segment analysis that incorporates metric distance alongside angular distance. This enables the analysis of different urban networks based not only on topological aspects but also on the distance people travel, i.e., the range of their daily lives.

In particular, by setting a metric range, they demonstrated the possibility of conducting patchwork analysis at a local level, typically at a radius of around 500 meters. Additionally, Turner (2007) demonstrated the effectiveness of using street center lines in performing space syntax, providing a rational basis for many researchers to conduct their analysis with road center lines. Therefore, it can be inferred that the most effective method of performing space syntax currently is angular segment analysis (ASA) based on road center lines with metric thresholds. It is evident that accurately defining segment lines of the study area and setting appropriate analysis thresholds according to research objectives are crucial for conducting space syntax analysis effectively.

Space syntax analysis starts by dividing the overall spatial structure into segment lines. It calculates various values such as depth, connectivity, control, and integration. Depth refers to the number of spaces traversed when moving from one space to another. When a space is traversed through a segment line, the depth value increases by one, indicating lower accessibility as depth increases. Connectivity represents the extent to which a line interacts with other lines. A higher value is assigned when connected to a larger number of other lines. Control and integration are more comprehensive indicators. Control values the influence of a segment line on movement occurring in the surrounding spaces. Control is also referred to as "choice" because there is a higher likelihood of using segment lines with higher control (choice) when arbitrary movements occur within the network.

Integration is the fundamental indicator extensively used in interpreting urban structure. It primarily represents the probabilistic distribution of movement occurring along a segment line. It is determined based on factors such as average depth and relative depth, where a higher value is assigned to segment lines with frequent connections to other spaces and shorter connection depth. Integration includes global and local integration. Global integration values the entire network without considering depth distinctions, while local integration focuses on a limited area within a specific threshold to understand localized distribution.

Among various indicators of space syntax, control and integration are the most adequate indicators to illustrate the connectivity of a network. By calculating these indicators for road and green networks, we can understand their compositional characteristics. We can comprehensively evaluate the centrality, potential for movement, and spatial cognition within each segment of the overall system. However, using these indicators without calibration presents a limitation in comparing different cities. Space syntax analysis results can vary depending on the extracted axial maps, such as resolution, scale, number of axes, and total area, which differ among cities. To overcome these limitations, normalized angular choice (NACH) and normalized angular integration (NAIN) were introduced. Hillier, Yang, and Turner (2012) developed normalized values of control and integration to enable quantitative comparison among cities. This normalization overcomes the absolute differences in the size of cities and allows for evaluating the relative importance of segments within each city. Therefore, in this study, we aim to utilise NACH and NAIN for intercity comparisons.

3. Materials and Methods

3.1. Study Area

In this study, four cities were selected from the second- and third-phase new cities (two from each) in the Seoul metropolitan area to examine the changes in the connectivity of green networks. The second-phase new cities aimed to alleviate the side effects of the first-phase new cities by increasing the proportion of green areas and actively adopting linear design techniques. Additionally, they targeted to improve the livability within the cities by reducing population density compared to the first-phase new cities. There are total of 10 second-phase new cities, starting with Hwaseong-si Dongtan-1 in 2001, and construction is still ongoing. The average site area of the second-phase new cities is 12.41km^2, the average population capacity is 155.9 thousand people, and the average population density is 127.8people/ha.

The third-phase new cities were planned to be more environmentally friendly and self-sufficient than the second-phase new cities. As the completion of the second-phase new cities approached, the land-use plans for the third-phase new cities were gradually being officialised. The third-phase new cities are smaller in scale compared to the second-phase new cities and have a higher proportion of self-sufficient area. The goal is to minimize the risks associated with excessive development of large sites and create multiple small cities that are as close as possible to Seoul. Furthermore, many of the third-phase new cities have lifted development restrictions in the metropolitan region, aiming to maximize transportation efficiency. (Debates for and against the lifting of development restrictions continue to emerge). Among these third-phase new cities, there are six where land-use plans have been officially announced. The average site area is 5.5km^2, the average population capacity is 68 thousand people, and the average population density is 125.7people/ha. These second- and third-phase new cities exhibit different planning trends over time and show considerable differences in scale and functional distribution. Therefore, in this study, it is necessary to select cases that can represent the planning trends of each period and allow for comprehensive comparisons between them. Accordingly, Dongtan-1(Dongtan) and Wirye were selected from the second-phase new cities, and Wangsuk-2(Wangsuk) and Gyosan were selected from the third-phase new cities.

Dongtan-1 and -2 is located in the southern part of the metropolitan region, surrounded by the Gyeongbu Expressway, which connects Seoul and Busan. It was developed sequentially with Dongtan-1 to the west and Dongtan-2 to the east. Currently, Dongtan-1 is in a completed state, while Dongtan-2 still has many undeveloped areas. In this study, we aim to analyse the green network system of Dongtan-1, which incorporates a unique radial form. It consists of a large central park and dispersed green networks intersecting in circular grids. Smaller green networks intertwine and intersect with radial road system to form a radial green network itself. Wirye is located on the border of Seoul's Songpa-district, Hanam-city and Seongnam-city, making it easily accessible to various parts of the metropolitan region. It is located adjacent to the development restriction zone and is characterized by the presence of the Changgok stream, flowing from the Cheongnyangsan mountain. In Wirye, the natural features of the southern Changgok stream were preserved and utilised, while another waterway was secured in the north, forming two river axes flowing east and west to activate the green network. Additionally, commercial spaces linked to the green axis were established in the city center to promote the coexistence of green areas and commercial activities.

Table 1. Indices of Seoul Metropolitan Area New Cities (2nd and 3rd Phase)

Phase	City	Administrative Region	Area [km^2]	Housing [1,000]	Pop. [1,000]	Pop. Density [pers./ha]	Project Duration
2nd	Pangyo	Sungnam-si, Gyeonggi-do	8.9	29.3	88	98	2003-2017
	Dongtan-1	Hwaseong-si, Gyeonggi-do	9.0	41.5	126	139	2001-2018
	Dongtan-2	Hwaseong-si, Gyeonggi-do	24.0	116.5	286	119	2008-2025
	Gimpo	Gimpo-si, Gyeonggi-do	11.7	61.3	167	146	2002-2017
	Woonjeong	Paju-si, Gyeonggi-do	16.6	88.2	217	130	2003-2023
	Gwanggyo	Suwon-si, Gyeonggi-do	11.3	31.3	78	69	2005-2019
	Yangju	Yangju-si, Gyeonggi-do	11.2	63.4	163	146	2007-2018
	Wirye	Songpa-gu, Seoul Hanam-si, Gyeonggi-do Sungnam-si, Gyeonggi-do	6.8	44.8	110	163	2008-2024
	Godeok	Pyeongtaek-si, Gyeonggi-do	13.4	57.2	140	104	2008-2020
	Geomdan	Seo-gu, Incheon	11.2	74.7	184	164	2009-2025
3rd	Wangsuk-1	Namyangju-si, Gyeonggi-do	9.4	54.0	125	133	2019-2028
	Wangsuk-2	Namyangju-si, Gyeonggi-do	2.4	14.0	35	146	2019-2028
	Gyosan	Hanam-si, Gyeonggi-do	6.3	33.0	78	114	2019-2029
	Gyeyang	Gyeyang-gu, Incheon	3.3	17.0	41	123	2019-2026

	Chang-neung	Goyang-si, Gyeonggi-do	7.9	36.0	86	109	2020-2029
	Daejang	Bucheon-si, Gyeonggi-do	3.4	19.0	44	129	2020-2029

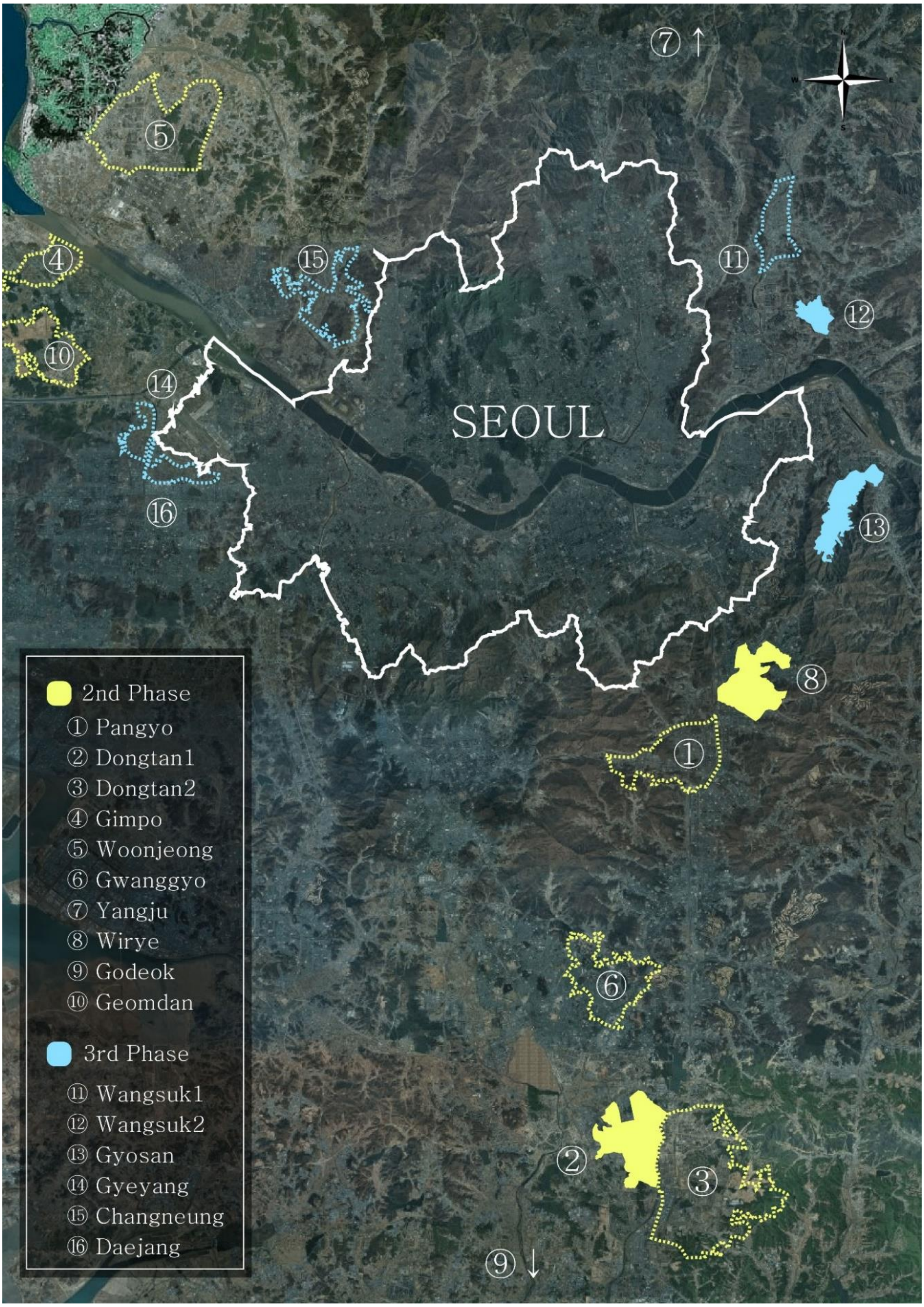

Figure 1. New Cities of Seoul Metropolitan Area (2nd and 3rd Phase)

Wangsuk is located in the northeast of Seoul, in Namyangju City, and it is positioned between Gangwon-province and Seoul, especially in proximity to the Han-river. In particular, the adjacent area has seen active development of numerous new cities or development sites including Yangjeong and Dasan. Wangsuk is relatively smaller in scale compared to other cases and also features the utilisation of existing waterways to create a large green area in the confluence area. Gyosan is located in Hanam-City, to the south of Wangsuk and the southeast of Seoul. It is planned to be constructed as an expansion area of the recently completed Hanam-Misa-district. It is characterized by the significant lifting of development restrictions and ongoing construction. Therefore, Gyosan is surrounded by mountains on all sides and is planned as a city centered around a river that flowed inwards from surrounding valleys. The central green axis is formed along the river, and it is worth noting that following this river towards the north leads directly to the Han-river.

Dongtan is currently in a completed state, while Wirye has completed construction for only about half of its area. The two third-phase new cities have only formalized their land-use plans yet to reach the stage of construction. Therefore, if we were to analyse each case based on the current topographic map or land-use status, the content would be completely different, and the resolution would vary for each case. Therefore, in this study, while referring to the information regarding the current situation, we will primarily analyse the official land-use plans announced for each city. Open spaces such as rivers, transformed water bodies, parks, special pedestrian paths, and plazas that are reflected in the land-use plans are all included in the road and green networks. However, elements such as roads within residential complexes, stroll paths within green areas, and commercial arcades, which are not designated in the land-use plans are excluded from the networks.

Table 2. Green Indices of the New Cities

	Dongtan	Wirye	Wangsuk	Gyosan
Area [km^2]	9.03	6.77	2.39	6.31
Green Area [km^2]	2.53	1.73	0.79	2.21
Percentage [%]	28	25.6	33.4	35

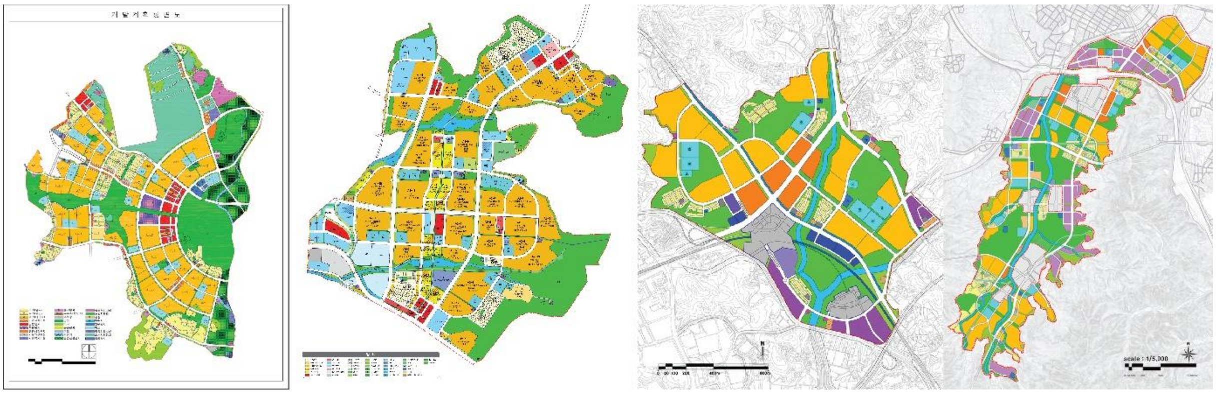

Figure 2. Land-Use Plan of the New Cities (From the Left, Dongtan, Wirye, Wangsuk, Gyosan)

3.2. Development of Green Synergy Indicators

In order to evaluate the synergy of road and green networks for the four cities, spatial syntax theory will be utilised. However, simply using spatial syntax indicators is not sufficient for analysing the connectivity between different facilities or networks; it requires calculations or combinations of the indicators. Kim, S., Y. Kim and Ji (2021) analysed the relationship between the change in building use and the spatial structural characteristics of roads in the central area of Gunsan City by introducing new evaluation indicators induced from original space syntax indicators. They derived spatial structure values at the store level to understand the spatial characteristics of commercial and non-commercial buildings scattered along the roads. They performed spatial syntax analysis on the roads and calculated the integration values of the roads facing the entrances of each store, which were then used to determine the integration level of each store. Similarly, Kim and Choi (2013) developed evaluation indicators for the connectivity of green spaces for linear and areal green spaces respectively. For linear green space integration, they multiplied the integration level of the road installed along the linear green space by the area of the linear green space to calculate the integration level. For areal green space integration, similar to the example of buildings, they multiplied the integration level of the road facing the entrances by the area of the areal green space. They applied the concept of green space integration to the first- and second-phase new cities and conducted an analysis on changes in the green networks. In this study, similar to the previous cases, the spatial syntax results for roads and the arrangement of green spaces will be combined to create new evaluation indicators. Based on these indicators, the green networks of the second- and third-phase new cities will be analysed.

Kim and Choi (2013) incorporated only one road's spatial syntax value for each green space into the evaluation indicator. However, assuming that only one road is connected to each green space has limitations when analysing the complex and intricate green network of the present. Therefore, we are introducing a new concept of green space syntax indicators. The proposed indicators will reflect the spatial syntax values of all roads adjacent to each green space. In other words, if multiple roads or green axes are connected to a green space, the spatial syntax values of all those roads will be considered and allocated to that green space. Moreover, to facilitate the comparison between cities using these indicators, we employed NACH and NAIN for calculations. The first two indicators are green angular choice (GACH) and green angular integration (GAIN) which are allocated to each green space. They are the sum of choice values and integration values, respectively, of the connected segment lines, which include not only one but all the linked networks. Then another two indicators, green choice ratio (GCR) and green integration ratio (GIR) are introduced to quantify the synergy of the cities. GCR is a ratio of GACH over NACH and GIR is a ratio of GAIN over NAIN. Both indicators show the amount of synergy the road and green networks of each city has in consideration of original space syntax values. Hence, higher GCR means that the green network is highly centered and crucial in connecting the overall network and higher GIR means higher synergy between the road and green networks.

Table 4. Definition of Green Synergy Indicators

Green Synergy Indicator	Calculation Formula
Green Angular Choice [GACH]	$\mathrm{GACH} = \frac{\sum(Area_{green}) \times (NACH_{linked\ segment})}{\sum Area_{green}}$
Green Angular Integration [GAIN]	$\mathrm{GAIN} = \frac{\sum(Area_{green}) \times (NAIN_{linked\ segment})}{\sum Area_{green}}$
Green Choice Ratio [GCR]	$\mathrm{GCR} = \frac{\mathrm{GACH}}{\mathrm{NACH}}$
Green Integration Ratio [GIR]	$\mathrm{GIR} = \frac{\mathrm{GAIN}}{\mathrm{NAIN}}$

3.3. Analysis Framework

The analysis consists of four stages: segment map production, green space extraction, spatial syntax analysis, and evaluation indicators calculation. First, we used AutoCAD 2022 to create segment maps. Based on the officially designated land-use plans, segment maps were manufactured for each city. Segment maps include not only roadways, sidewalks, and pedestrian bridges but also the green spaces, plazas, walking paths within green areas, and waterfront areas specified in the land-use plans. Previous studies primarily focused on analysing roadways, which had limitations in reflecting human movement. In this study, we aimed to incorporate as many pathways for pedestrian movement as possible. According to Turner (2004), spatial syntax is influenced by the extent of segment maps, and 'edge effect' occurs at the boundaries where the networks break. For this study, the target areas are mostly constructed near development-restricted zones and it is expected that the influence of such peripheral areas will be minimal. In addition, to further minimize the 'edge effect', the nearby crucial road network and major connections were included in the segment maps.

Next, green spaces were extracted based on the land-use plans. Using boundary lines, the distribution of green spaces in each city was determined. For area-based green spaces, extraction was relatively straightforward. However, for linear green spaces, which often had interconnected relationships, separate criteria were established to distinguish different types of green spaces. The objective of this study was to calculate all road networks connected to a specific green space. Therefore, green areas serving as pathways were initially identified, followed by the extraction of smaller green spaces (buffer spaces and connecting spaces). Additionally, during the green space extraction process, all waterways were included as part of the green spaces. Although direct access by pedestrians is not possible, waterways and their usage through waterfront areas, along with bridges offer both functional and scenic effects similar to green spaces. Thus, waterways were classified as a type of green space for the analysis.

For the space syntax analysis and evaluation indicators calculation, we utilized QGIS 3.22.4. The UCL Space Syntax Lab provides depthmapXnet, a tool that enables spatial syntax analysis within QGIS. As determined through theoretical considerations, we performed angular segment analysis for the road networks for each new city. The radius type was set to metric, considering the influence of pedestrian movement based on distance, and we conducted analyses at both the global (n) and local (400m, 800m) levels. The space syntax values calculated for each segment were directly entered into the attribute tables of the shapefiles in QGIS.

Lastly, we combined the results of the analysis with the green spaces to calculate the evaluation indicators. Using the join function in QGIS, we identified the segments connected to each green space and assigned the corresponding space syntax values to the respective green spaces. We employed the 'Join Attributes by Nearest' function, without imposing any restrictions on the 'maximum nearest neighbor', and limited the 'maximum distance' to 30m. This ensured that segments located beyond 30m from a specific green space were not assigned to it. As a result, multiple segments directly connected to each green space and their corresponding space syntax values were correctly assigned. After the assignment, we used StataSE 17 to calculate the synergy evaluation indicators and conduct statistical validation.

Figure 3.45 Road and Green Networks of the New Cities (Made Using QGIS 3.22.4)

4. Results

4.1. Spatial Structural Characteristics of the Four New Cities

Using the principles of space syntax, I first examined the overall spatial structures of the four new cities. The findings reveal distinct characteristics in terms of control and integration values within the urban networks. Figure 4 is the visual result of space syntax analysis and displays the value of NAIN and NACH of the segments through the difference in thickness; thicker the line, higher the value. Dongtan features a radial road network centered around the central park on the east side. Consequently, the integration values are high for the semi-circular roads connected to various linear-crossing road networks, particularly in the dense commercial area at the city center. The control value shows that the roads surrounding the central park have the highest values, indicating that the central park serves as a convergence point for all roads in Dongtan. Wirye exhibits a uniform distribution of green spaces throughout the city, without a specific central point. Notably, the outskirts of the city have abundant green spaces that connect with the peripheral natural environment. The integration value is highest in the city center and the southern district, while the northern region, with sparse road extensions, shows relatively lower integration. In terms of control, the main roads in the southern central area have the highest values, indicating their frequent use as pathways within Wirye.

Wangsuk displays a similar distribution of green spaces to Wirye, and the integration value is highest along the arterial roads. Moreover, the integration value is significant for the green axes that traverse the central green axis and the riverside axis. In terms of control, the areas surrounding the large park in the south and the arterial road in the northwest exhibit the highest values. Gyosan, characterized by its long-shape in the north-south direction, has major north-south road networks with grid-like green spaces aligned along them. The integration and control values are both high for the main north-south road networks, indicating their prominence within the city.

Table 5. NACH and NAIN of the New Cities

		2nd generation		3rd generation	
		Dongtan	Wirye	Wangsuk	Gyosan
NACH	Global	0.92	0.823	0.869	0.731
	Local(400m)	0.793	0.551	0.707	0.453
	Local(800m)	0.949	0.759	0.858	0.63
NAIN	Global	1.066	1.083	1.234	1.088
	Local(400m)	1.742	1.558	1.616	1.343
	Local(800m)	1.627	1.591	1.54	1.356

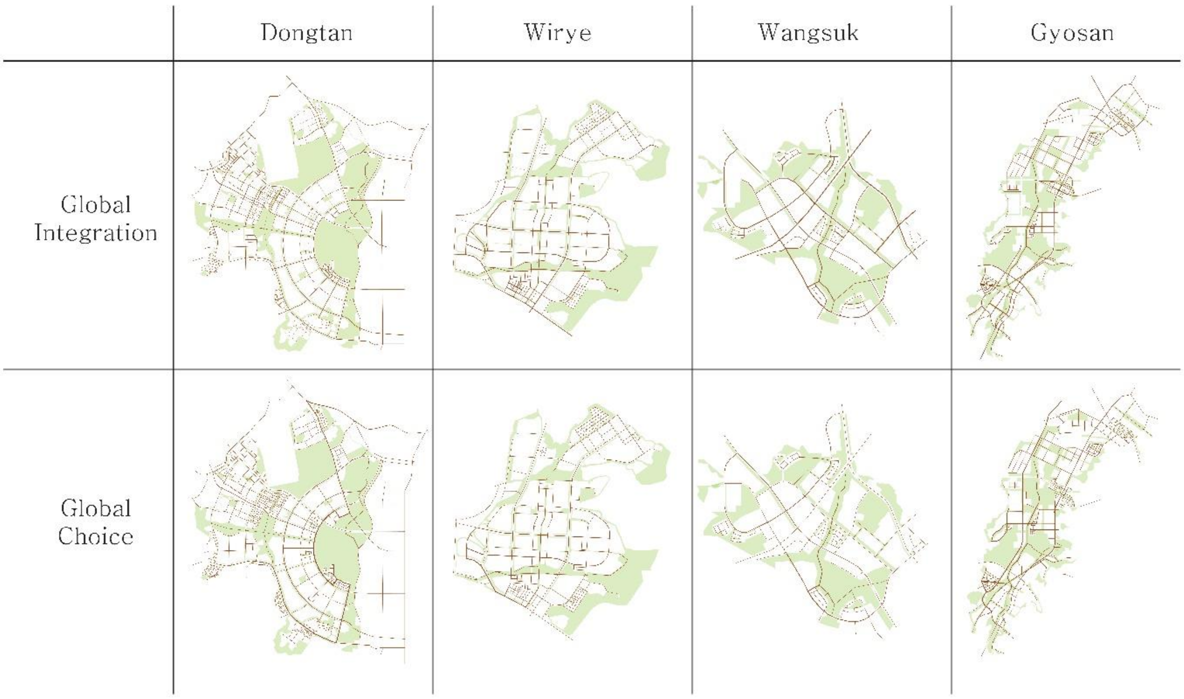

Figure 4. Space Syntax Result of the New Cities (Values Expressed in Thickness)

Compared to the second-phase new cities, the third-phase new cities generally have higher integration values and lower control values. This suggests that the road networks in the third-phase new cities are designed with improved connectivity and reduced centrality. However, when comparing local integration values, the second-phase new cities show higher values, indicating that they are more effectively designed for pedestrian movement. This difference might be due to the lack of detailed road designs in the planning of the third-phase new cities. The introduction of various design elements such as white-zoning has led to the incorporation of many features that are not reflected in the land-use plans. It is necessary to reassess these aspects after detailed parcel-based designs are completed. Additionally, the increase in self-sufficient land and the rise in industrial land use in the third-phase new cities may have contributed to the lower local integration values. Industrial land, generally characterized by larger scale, can disrupt the continuity of road networks at a finer level. Nevertheless, from a macroscopic perspective in the land-use planning stage, it is evident that the pedestrian-oriented neighborhood design in the third-phase new cities has been spatially compromised compared to the second-phase new cities.

4.2. Green Synergy of the Four New Cities

Through analysing the green synergy indicators for the cities, the following results were observed. Firstly, among the four cities, Dongtan showed the highest GCR (18.49), which indicates a strong centrality of the network, and in the case of Dongtan, this can be attributed to the presence of a large central park. Although GIR (13.48) in Dongtan is lower compared to the third-phase new cities, it is significantly higher than that of Wirye. Dongtan garnered attention as a city with innovative green space planning when the second-phase new cities were first established in the early 2000s. It received praise for its grid network of roads and green spaces extending from the central park, which is now reflected in the high GIR. Local GCRs (15.20, 17.23) decreased as the range decreased. This indicates that the distinctiveness of the central park is not clearly manifested at a local level. In other words, while the role of the central park is evident at a citywide scale, green spaces with centrality are not readily visible at a local level. This effectively demonstrates the characteristics of Dongtan's green space network, which is primarily composed of linear parks. Local GIRs (15.40, 15.76) were higher than the global GIR, indicating that Dongtan's green space network is effectively connected even at a local level. Particularly, the higher values at a local level indicate that green spaces are better connected in the pedestrian range of neighborhoods. In summary, Dongtan demonstrates high GCR with a central park and high GIR with a grid network of roads, even at a local scale, indicating a high synergy within linear parks.

Wirye recorded the lowest values in all indicators. Unlike Dongtan, Wirye has a green space network similar to other second-phase new cities. Many second-phase new cities utilised development restriction zones on the outskirts of the city to secure the ratio of green spaces, and this characteristic is also evident in Wirye. As a result, its GCR (11.54) and GIR (10.05) were the lowest among the target areas. At a local level, it showed even lower value, highlighting the limitations of green spaces concentrated at the outskirts of the city. Wirye’s commercial and residential areas are primarily located in the city center, while green spaces are mainly situated on the outskirts. This indicates that the overall synergy at a local level is diminished due to the segregation of main living areas and green spaces.

Wangsuk ranked third in GCR (17.68) but showed significantly higher values compared to

Wirye. Wangsuk does not have a concentrated large green space in a specific area but rather has multiple medium-sized green spaces distributed throughout the city. This is why the GCR is relatively low. However, Wangsuk shows high local GCRs (18.12, 17.34), which are the highest among the target areas. This indicates that the secondary central green spaces are functioning as central parks at the neighborhood level. Medium-sized green spaces must be effectively connected as networks. Wangsuk's GIR (14.77) ranked the highest among the target areas. It also showed high local GIRs (15.55, 13.99), with the integration rate at the 400m scale ranking the highest. This demonstrates the excellent synergy of Wangsuk's green spaces, not only in the overall range but also at a local scale. In sum, Wangsuk demonstrates high synergy at a local level due to the dispersed green spaces throughout the city and the effective network of roads connecting each green space.

Gyosan showed the second-highest GCR (18.09) right behind Dongtan, and its absolute size was competitively large. Although not as distinct as Dongtan, Gyosan also has a long central green space centered around the river in north-south direction, and the centrality of this green space is evident through GCR. However, it showed lower local GCRs (12.66, 14.81) compared to Dongtan and Wangsuk, indicating that there are fewer green spaces with centrality at a local scale. Unlike Wangsuk, green spaces in Gyosan do not play a central role in each neighborhood unit. Gyosan's GIR (14.62) was similar to that of Wangsuk. This indicates that Gyosan, as a third-phase new city, also exhibits a high level of synergy. However, at a local level, particularly in the 400m range, it showed lower values (14.42, 15.26) compared to Wangsuk, indicating relatively lower synergy at a local scale. In conclusion, Gyosan also shows a high GCR and GIR, and the long rectangular central park is performing its role effectively. However, it exhibits slightly lower synergy at a local level compared to Wangsuk.

Table 6. Green Synergy Indicators of the New Cities

		2nd generation		3rd generation	
		Dongtan	Wirye	Wangsuk	Gyosan
GACH	Global	17.01	9.50	15.37	13.22
	Local(400m)	12.05	5.50	12.81	5.73
	Local(800m)	16.35	8.40	14.88	9.33
GAIN	Global	14.37	10.89	18.22	15.91
	Local(400m)	26.83	15.08	25.13	19.37
	Local(800m)	25.64	15.73	21.55	20.69
GCR	Global	18.49	11.54	17.68	18.09
	Local(400m)	15.20	9.99	18.12	12.66
	Local(800m)	17.23	11.07	17.34	14.81

GIR	Global	13.48	10.05	14.77	14.62
	Local(400m)	15.40	9.68	15.55	14.42
	Local(800m)	15.76	9.89	13.99	15.26

Based on the analysis of synergy, a comparative study between the cities was conducted. The analysis results showed that the GCR was high in order of Dongtan-Gyosan-Wangsuk-Wirye, while the GIR was high in order of Wangsuk-Gyosan-Dongtan-Wirye. Control value differed according to the scale of analysis and showed the difference of centrality in terms of scale and neighborhood-level of the four cities. Regarding integration, both Wangsuk (14.77) and Gyosan (14.62) showed significantly higher values compared to Dongtan (15.40) and Wirye (10.05). This indicates that the green spaces in the third-phase new cities are more efficiently connected to the road network compared to the second-phase new cities. However, at a local level, Dongtan (15.40) had the highest GIR, while Wangsuk and Gyosan also showed higher values compared to Wirye. Overall, the third-phase new cities demonstrated superior green space arrangement and connectivity compared to the second-phase new cities, indicating a higher level of synergy.

5. Conclusion

Based on the application of space syntax theory to the representative second- and third-phase new cities, the following key conclusions were drawn regarding the synergy between road and green networks. First, in terms of road networks, the third-phase new cities showed higher integration and lower control compared to the second-phase new cities. This indicates that the overall connectivity of street networks in the third-phase new cities is good, with a dispersed pattern rather than a concentration of networks in central locations. However, from a local perspective, they exhibited lower connectivity compared to Dongtan, although they showed higher values compared to Wirye, which is expected to have similar characteristics to typical second-phase new cities. Second, regarding the synergy of the two networks, the analysis revealed that the third-phase new cities also demonstrated superiority over the second-phase new cities. Particularly, the global GIRs of the third-phase new cities were significantly high, indicating efficient connections throughout the road and green networks. However, the local integration ratio in the third-phase new cities was lower than that of Dongtan, suggesting the need for improvement in the design of neighborhood units.

In future research, we intend to increase the number of target sites to strengthen the statistical basis. Specifically, further analysis of the synergy of other second-phase new cities, which will soon all be constructed, should be conducted. Additionally, as the construction of second- and third-phase new cities progresses, more accurate analysis results can be obtained by considering the detailed street networks of completed new cities, including the interconnections between residential complexes, waterways, green spaces and commercial open spaces. In this study, the analysis of detailed street networks was limited due to the use of land-use plans rather than the current state of the cities. Through this research, new quantitative evaluation indicators for synergy, GACH, GAIN, GCR and GIR, were defined and applied to the analysis of major new cities. Through future improvements, it is proposed to refine the indicators and provide a more accurate and precise evaluation framework. This can be utilised not only for new cities but also for diagnosing the synergy of road and green networks in existing urban areas, enabling effective urban regeneration that reflects citizens' demand for green spaces.

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Appendix: Descriptive Statistics of Space Syntax Result

Descriptive Statistics of Space Syntax Result (Dongtan)

Variable	Obs	Mean	Std. Dev.	Min	Max
Angular Connectivity	1036	.658	.754	0	4.034
Connectivity	1036	1.967	.87	0	5
Segment Length	1036	117.395	168.265	1.611	3216.177
Choice	1036	1129.011	2792.861	0	19887
Choice(400m)	1036	30.211	71.793	0	628
Choice(800m)	1036	76.491	134.311	0	780
Integration	1036	24.488	47.109	0	1024
Integration(400m)	1036	26.716	70.972	0	1152
Integration(800m)	1036	22.587	47.811	0	1024
Node Count	1036	67.566	74.99	1	208
Node Count(400m)	1036	10.858	9.892	1	44
Node Count(800m)	1036	17.718	14.296	1	61
Total Depth	1036	323.703	477.662	0	1944.883
Total Depth(400m)	1036	12.415	21.429	0	113.77
Total Depth(800m)	1036	28.772	40.259	0	190.445
NACH	1036	.92	.615	0	2.199
NACH(400m)	1036	.793	.645	0	2.075
NACH(800m)	1036	.949	.647	0	2.28
NAIN	1036	1.066	.632	.286	3.627
NAIN(400m)	1036	1.742	.737	.49	4.488
NAIN(800m)	1036	1.627	.792	.483	4.279

Descriptive Statistics of Space Syntax Result (Wirye)

Variable	Obs	Mean	Std. Dev.	Min	Max
Angular Connectivity	348	.711	.762	0	3.133
Connectivity	348	1.816	.964	0	5
Segment Length	348	171.771	192.622	5.686	1570.909
Choice	348	179.04	329.253	0	1924
Choice(400m)	348	5.937	13.002	0	104
Choice(800m)	348	17.451	29.053	0	208

Integration	348	19.405	76.947	0	1024
Integration(400m)	348	9.417	95.091	0	1024
Integration(800m)	348	20.688	77.898	0	1024
Node Count	348	25.431	22.487	1	67
Node Count(400m)	348	5.655	4.043	1	22
Node Count(800m)	348	9.046	5.914	1	23
Total Depth	348	64.822	79.132	0	323.68
Total Depth(400m)	348	.055	1.205	0	8
Total Depth(800m)	348	8.795	10.865	0	56.41
NACH	348	.823	.638	0	1.985
NACH(400m)	348	.551	.581	0	1.767
NACH(800m)	348	.759	.65	0	1.896
NAIN	348	1.083	.48	.333	2.884
NAIN(400m)	348	1.558	.592	.66	3.299
NAIN(800m)	348	1.591	.627	.466	3.475

Descriptive Statistics of Space Syntax Result (Wangsuk)

Variable	Obs	Mean	Std. Dev.	Min	Max
Angular Connectivity	245	.696	.704	0	3.132
Connectivity	245	1.894	.792	0	4
Segment Length	245	110.298	104.083	12.844	989.754
Choice	245	155.559	250.711	0	1300
Choice(400m)	245	10.796	17.231	0	86
Choice(800m)	245	34.927	54.235	0	340
Integration	245	15.423	8.141	0	40.96
Integration(400m)	245	16.627	12.737	0	78.769
Integration(800m)	245	16.11	10.645	0	83.592
Node Count	245	22.461	18.574	1	52
Node Count(400m)	245	7.633	4.855	1	22
Node Count(800m)	245	12.62	9.27	1	39
Total Depth	245	49.21	56.372	0	211.117
Total Depth(400m)	245	6.837	8.692	0	39.668
Total Depth(800m)	245	17.008	20.646	0	87.668
NACH	245	.869	.657	0	2.09
NACH(400m)	245	.707	.6	0	1.808
NACH(800m)	245	.858	.655	0	1.933
NAIN	245	1.234	.566	.538	3.227
NAIN(400m)	245	1.616	.613	.68	3.197
NAIN(800m)	245	1.54	.686	.596	3.78

Descriptive Statistics of Space Syntax Result (Gyosan)

Variable	Obs	Mean	Std. Dev.	Min	Max
Angular Connectivity	450	.796	.775	0	4.181
Connectivity	450	1.747	.899	0	4
Segment Length	450	160.908	186.981	10.494	1321.232
Choice	450	123.998	223.494	0	1200
Choice(400m)	450	5.009	9.469	0	64
Choice(800m)	450	17.553	34.698	0	220
Integration	450	11.468	8.957	0	68.267
Integration(400m)	450	12.795	26.178	0	512
Integration(800m)	450	11.867	11.033	0	104.727
Node Count	450	18.093	16.398	1	51
Node Count(400m)	450	5.22	3.707	1	17
Node Count(800m)	450	8.218	6.405	1	29
Total Depth	450	43.389	57.457	0	248.012
Total Depth(400m)	450	3.93	5.37	0	27.738
Total Depth(800m)	450	9.27	12.177	0	53.484
NACH	450	.731	.66	0	2.061
NACH(400m)	450	.453	.534	0	1.487
NACH(800m)	450	.63	.619	0	1.745
NAIN	450	1.088	.496	.385	3.22
NAIN(400m)	450	1.343	.48	.572	3.449
NAIN(800m)	450	1.356	.559	.502	3.721