Summary

In this paper, we developed a comprehensive framework to assist local government in implementing smart growth principles into their cities growth plan towards the goals of sustainability. As each city has its own unique characteristics and constraints, two cities more often than not attain different levels of success when implementing the same set of smart growth policies. We have identified this as one of the main issues in the development of our two models.

Using Shannons Entropy method in multi-attribute decision-making, we first created a metric that measures the success of a citys urban planning initiatives over the years through a set of seventeen indicators. While many sustainability indexes have been developed to compare among cities, few are intended for a specific city to measure its progress, thus showing the relevance of our metric.

Our second model, original and carefully thought out, utilized decision linear programming to devise an algorithm that allocates a citys limited budget to a set of initiative candidates and rank each initiative based on a potential index. A notable strength of this model is that it provides a handy and reliable approach for urban planners to optimize their budget while accomplishing all aspects of sustainability.

Durham, a city in the U.S. southern state of North Carolina, and Liverpool, a major port city in England serve as our case studies. After running simulations on each citys reported data, we offered insights into the citys growth needs and redesigned its growth plan. In regards to Durham, results from our simulation correspond to the current development focus of the city, specifically public protection and economic development. Liverpool's development index shows unpredictable fluctuations and a potential decline after 2014. From our result analysis, we recommend that the city increase its smart growth initiatives, particularly towards housing and transportation.

In practice, our models proved to be efficient in computation. They are tailored to the specific needs of cities and at the same time can be useful in comparing between them if used with a consistent set of indicators and initiatives. We have also supplemented our analysis with extensive data collection. Lastly, we are confident that it accomplishes in evaluating and designing urban plans, and possesses great potential for future improvement.

Optimize Urban Planning with a Focus on Smart Growth

ICM Contest Question E

Team # 70304

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Contents

1 Introduction

1.1 Background

Urbanization, or the shift of population from rural to urban areas, is one of the defining aspects of the 21st century and perhaps the future. The United Nation estimates about 54 percent of the world population living in cities in 2014 and projects that number to reach 66 percent by 2050. This means that 2.5 billion people will be added to the urban population, of which the majority will concentrate in Asia and Africa [1].

This phenomenon directly leads to a complex challenge of maintaining the livelihood and quality of human life in cities. More important than ever are measures that enable cities to accommodate the increasing flow of people and ensure availability of as well as equitable access to resources and services.

The United Nation identifies the three interdependent pillars of sustainable development as economic prosperity, social equity and environmental sustainability [2]. As such, for a city that gears its policy towards the goals of sustainable development, we are interested in examining its success in attaining these objectives.

Smart growth is a popular urban planning theory that aims to address the issues of how and where to accommodate new development and redevelopment [3]. Its practices advocate preservation of green space, more compact communities, affordable housing and transportation choices to name a few. However, smart growth's effectiveness in achieving sustainability is often debated among critics and policy makers, partially due to the fact that each city has its own unique characteristics and conditions. As such, cities more often than not attain different levels of success when implementing the same set of smart growth policies. We have identified this as one of the main issues to address in the development of our model.

1.2 Defining the problems

Accordingly, our goal is to develop a comprehensive framework to assist ICM or local government in evaluating and implementing the smart growth theory into city design so as to promote urban sustainability basing on its three pillars. In order to achieve this goal, we follow a four-step procedure.

The first step is to devise a metric that measures the success of urban planning of a city based on significant indicators of economic, environmen-

tal and social sustainability.

The second step is to create a model that can design a growth plan for a city basing on its budget constraint, current initiatives, and costs. This model would allow for a selection of a set of initiatives that maximizes the success of the city plan, as well as a ranking of the initiatives' potential.

The third step is to carry out a simulation of our models on the two cities: Durham, North Carolina (USA) and Liverpool (England, UK). This process includes intensive research of the two cities.

In the final step, results were synthesized to provide an insightful comparison between the two cities.

2 Model to measure a city's success in urban planning

Assumptions

1. Success of planning initiatives reflects on components of the three pillars of sustainability.
2. External factors outside of a local government's control have negligible impact on all indicators.
3. Within the chosen time frame, the weight of each indicator is a constant. This assumption is crucial in order for the Shannon's Entropy method [4] to be adapted. As such, the longer the time frame is, the more accurate model results are.
4. A definite list of indicators is sufficient to represent a city's state of being.

Methodology

Part 1: Select indicators

After thorough research[1], we have carefully constituted a list of indicators that meet the following criteria:

- The set of indicators must cover the three goals of sustainability of a city, in line with the definition used.

[1] for a list of existing sustainability indexes and indicators, see `http://ec.europa.eu/environment/integration/research/newsalert/pdf/indicators_for_sustainable_cities_IR12_en.pdf`

- Indicators are independent and not mutually related within each category.
- Data for indicators must be either available from institutional sources or easily collected.

Table 1 includes a list of indicators that we recommend as inputs to our model. Because choosing possible indicators is subjected to one's judgment, our first model was subsequently presented in a general form. Furthermore, in our case study, the specifics of some components were adjusted based on data availability of the city.

Category	Components	Indicators
Economy	Income level	Household median income
	Employment	Urban unemployment rate (%)
	Job growth	Increase in number of jobs created (%)
	Energy intensity	Total energy consumption (SEC per unit GDP)
Environment	Air quality	Air Quality Index (AQI)
	Waste management	Total amount of sewer spills or overflows (gallon)
	Water efficiency	Total water consumption (mil gallons per day per unit GDP)
	Urban density	Persons by square unit of urban area
	Energy efficiency	Energy saving (MWh)
	GHG emission	Emission of CO_2 (mil metric tons)
	Public green space	Area of public green space (%)
Society	Healthcare	Health insurance coverage(%)
	Mass transit usage	Passengers using public transit (per capita)
	Housing	House price to income ratio (dollars)
	Crime	Crime index
	Education	Adult literacy rates
	Pension	Pension security coverage (%)

Table 1: List of indicators recommended

Part 2: Metric formulation

In this model, Shannon's Entropy method was used to assign appropriate weight to each normalized indicator. The development index of each pillar of sustainability was then calculated.

Symbol	Description
m	number of years considered
x	number of economic indicators
y	number of environmental indicators
z	number of social indicators
a_{ij}	value of economic indicator i in year j
b_{ij}	value of environmental indicator i in year j
c_{ij}	value of social indicator i in year j
I	matrix of all indicator values $i = 1, \ldots, (x + y + z)$ and $j = 1, \ldots, m$
I^*	normalized matrix
w_i	weight of indicator i by Shannon's Entropy method
E_{1j}	economic development index of year j
E_{2j}	environment development index of year j
E_{3j}	social development index of year j
Q_i	sustainable development index of year j

Table 2: Notations for Model 1

Step 1: Normalize indicator values, $\forall(i, j)$

If the indicator is positively correlated to a city's growth:

$$I_{ij}^* = \frac{I_{ij} - \min\limits_{k=1\to m} I_{ik}}{\max\limits_{k=1\to m} I_{ik} - \min\limits_{k=1\to m} I_{ik}} \tag{1}$$

If the indicator is negatively correlated to city's growth:

$$I_{ij}^* = \frac{\max\limits_{k=1\to m} I_{ik} - I_{ij}}{\max\limits_{k=1\to m} I_{ik} - \min\limits_{k=1\to m} I_{ik}} \tag{2}$$

Note: for non-monotonic indicator value, one can still normalize using its absolute difference from an ideal value that is set by policy makers or the scholar community. The lower the difference from the ideal, the better, so equation (2) can be applied.

Step 2: Compute weights

$$h_i = -\frac{\sum_{j=1}^{m} I_{ij}^*}{\ln m}, \qquad d_i = 1 - h_i \qquad \text{and} \qquad w_i = \frac{d_i}{\sum_{j=1}^{x+y+z} d_j} \qquad \forall i \tag{3}$$

Step 3: Compute development index

$$E_{1j} = \sum_{\text{economic i's}} w_i I_{ij}^* \tag{4}$$

$$E_{2j} = \sum_{\text{evironmental i's}} w_i I_{ij}^* \tag{5}$$

$$E_{3j} = \sum_{\text{social i's}} w_i I_{ij}^* \tag{6}$$

$$S_j = E_{1j} + E_{2j} + E_{3j} \tag{7}$$

Strengths and limitations

i) Strengths

- Model computation can be easily done.
- Indicators' weights can be objectively determined as larger weights are assigned to indicators whose changes best represent the data trend.
- Categorization of indicators into three dimensions of sustainability allows one to look at changes in improvement index of each dimension over time.
- Model can be adapted to any selected list of indicators.

ii) Limitations

- The model relies heavily on the availability and accuracy of past data. Hence, it requires a considerable amount of research and data collection.
- This metric does not provide an upper limit for how large the index value can reach.

- Our model was not developed in order to compare success between cities; rather, its intended purpose was to enable policy makers to understand the success of their initiatives with respect to their own city.

3 Model to implement smart growth into city design by using linear programming

In order to design a city's growth plan founded on smart growth principles, we considered only reputable initiatives that have been successfully implemented in major world cities. In doing so, we were able to devise an algorithm that can adapt these initiatives to any other city, of course with minor modifications to suit each city's unique needs. We also chose a city's budget as the only constraint for the lack of time; however, our algorithm can be easily revised in order to take into account each city's unique characteristics, such as geographic condition, demographics, etc if these factors were not already reflected on the indicators.

Assumptions

1. Cities only have a fixed budget for their urban planning initiatives.
2. Any initiative has a limited budget allocation.
3. An indicator's change in value is directly proportional to the amount of money invested in corresponding initiatives.
4. For the sake of simplicity, indicators' impact is assumed to be either negative (-1), neutral (0) or positive (1) in absolute terms. A more rigorous relative scale should be developed later.
5. We also assume all the assumptions from our first model.

Methodology

We modeled this problem as a finite linear programming problem in an impact network of initiatives and indicators. The decision binary variable indicates whether to implement an initiative. The overall objective is to select a combination of initiatives that maximizes the development index, within the city's budget constraint.

Step 1: Determine a city's overall budget

Policy makers enter their own budget value as they run our framework to implement smart growth in their city of choice. In subsequent case studies, we estimated a city's budget for a fiscal year based on the local government's published reports from the most recent year.

Step 2: Research and obtain a list of notable initiatives

Due to the generality of our model, any list of sample initiatives can be used; in other words, the model was developed for flexibility. However, for demonstrative purposes, we researched and constituted a list of outstanding initiatives that met the following criteria:

1. demonstrated success when implemented in other major U.S. cities
2. intended to accommodate growth over a long time horizon
3. cost of implementation is publicly available
4. based on the ten principles of smart growth theory
5. won National Award for Smart Growth Achievement[2] in corresponding category

Step 3: Formulate and solve the linear programming problem

As mentioned in the assumptions, the value of A's entries follows the following assignment rule: A_{ij} is 1 if initiative i enhances indicator j, -1 if initiative i negatively impacts indicator j, and $= 0$ if neutral.

We use the following computations to approximate A^*:

$$d_i = \sum_{j=1}^{m} \mid A_{ij} \mid \qquad \text{and} \qquad A^*_{ij} = \frac{A_{ij}}{d_i} \tag{8}$$

Rank initiatives based on their potential index s_i :

$$s_i = \frac{\sum_{j=1}^{m} A^*_{ij} w_j b_i}{t_i} \tag{9}$$

[2]Environmental Protection Agency, https://www.epa.gov/smartgrowth/national-award-smart-growth-achievement

Initiative	City	Median Household Income of City(US$)	Estimated Cost (in US$ mil)	Smart Growth Principle
Revitalize mid-rise public housing site into a true mixed-income urban community	Jersey City, NJ	59537	64	3
Build an office/health center complex on main street which has been deteriorating in recent years	Neptune, NJ	59660	18.5	7
Build inter-municipal and affordable housing that connects adjacent neighborhoods	Woodstown, NJ	72905	20	3
Redevelop Food Co-op Market from a strip mall surrounded by parking lots into a street-facing, mixed-use development, with commercial space, offices, and affordable apartments	Brattleboro, VT	46899	12	1,2,7
Provide loans to build affordable housing for low-income families near transportation area	San Francisco, CA	88518	50	3, 8
Redevelop and revitalize the downtown area	Lancaster, CA	49057	41	5, 7
Invest in streets, sidewalks, and intersection improvements to support the South Corridor LRT	Charlotte, NC	54836	25	4
Use lottery proceeds to fund park and conservation programs	Colorado State	63909	5	6

Figure 1: List of some innovative smart growth initiatives in other U.S. cities used in simulation

Impact on each indicator j is quantified by:

$$y_j = w_j \sum_{i=1}^{n} x_i A_{ij}^* \tag{10}$$

Amount of improvement in all indicators is:

$$f = \sum_{j=1}^{m} y_j \tag{11}$$

To pick an optimal set of initiatives is to maximize f subject to the following:

1) $\sum_{i}^{n} x_i b_i \leq B$ (budget constraint)

2) $x_i \in \{0, 1\}$ (selection constraint)

Symbol	Description
n	number of initiatives
m	number of indicators
B	city's budget
b_i	cost for initiative i
t_i	estimated time for initiative i
x_i	initiative i
w_j	weight of indicator j from model 1
A	matrix of impact indicator
A^*	normalized matrix of impact coefficient
y_j	amount of improvement in indicator j
s_i	the potential index of initiative i
f	amount of improvement in all indicators

Table 3: Notations for Model 2

Strengths and limitations

A notable strength of our model is that it provides a handy and reliable approach for urban planners to optimize their budget while accomplishing all aspects of sustainability. As each city often has its own priority policy areas, our model can be modified to accommodate such matter. In the first model (Section 2), weight given to each indicator was determined objectively based on past data trends. However, these weights can be assigned subjectively by a city's urban planners as they see fit.

In subsequent case study, we run two methods of simulation. In the first simulation, we included only the sample smart growth initiatives. In the second simulation, we incorporated both the city's current initiatives and the list of researched sample initiatives. Doing so serves two meaningful purposes. Firstly, we hoped to provide the local government a way to determine which smart growth initiative best suits the need of their city. Secondly, by incorporating both current and sample initiatives, the local government can interpret the effectiveness of their current plan from another perspective.

The model is limited by the fact that its effectiveness is dependent upon the accuracy of data and careful evaluation of each initiative's potential implications. Yet in a way, this proves to be a strength; any mathematical model for a social issue is only practically sound when expert opinions are valued as inputs.

4 Case study: Durham, North Carolina

4.1 Current growth plan

Durham is a city in the U.S. southern state of North Carolina. It has a population of 254,620 as of 2016, which grew by 1.8% annually from 2010 to 2016. The urban density as of 2016 is 2,646 persons per square mile. The 2015 median household income is $52,106, which is approximately U.S. median household income [5]. Durham's topography is generally flat with a total area of 108.3 sq miles of which 0.84% is water [6].

Durham's current growth plan (2012-2020) consists of 18 long-term objectives with a total of 83 initiatives of which 56 initiatives were implemented during or after 2015, and 27 initiatives implemented before 2015 [5]. The city is currently interested in researching best practices for opportunities for improvements in many of its priority policy areas. A list of Durham's current growth plan principles is included in Figure 2 while more details about the specific initiatives are given in Appendix.

Six of its eighteen growth objectives are similar to five principles of smart growth. Specifically, the city has undertaken numerous planning efforts to improve access to transportation including upgrades of its buses and railways. Secondly, in order to facilitate development efforts, the city has worked to put into effect policies that streamline its development review process. The city of Durham also aims to promote increased access to affordable housing as available data have suggested a large percentage of its residents are cost burdened by sky-rocketing housing rental prices. Lastly, Durham has shown commendable efforts in expanding engagement with neighborhoods and empowering community to participate in development planning decisions. These initiatives resemble some approaches of smart growth theory.

However, it is critical to note that a large part of Durham's growth plan was formed based on the community's current needs and visions for growth. For example, the city focuses on increasing public safety and reducing high crime rates, which it has been troubled with for years. While it focuses little attention on environment, Durham works to attract and retain businesses in pursuit of a boost in its growing economic sector.

4.2 Evaluation of the current plan

Applying the first model, we evaluated the success of Durham's current initiatives using indicator data from the 2011-2015 time frame. As the ma-

Objectives	No of Initiatives	Smart Growth Principle
Business Retention and Recruitment	3	7
Business-Friendly Environment	4	9
Empowering the Community by Providing Easily Accessible and Usable Information and Data	5	10
Ensure that the City's infrastructure is properly managed to ensure optimal availability and operating efficiency	4	0
Establish an Exceptional, Diverse, and Engaged and Healthy Workforce	5	0
Expand engagement with neighborhoods to ensure residents feel empowered to preserve or improve the quality of their neighborhoods building connections between people and programs	5	10
Facilitate High Survivability of Fire, Medical, and other Hazardous Emergencies	4	0
Foster a Culture of Innovation to Promote Operational Efficiencies and Deliver the Best Outcomes for Residents.	6	0
Improve Public Perception of Safety	3	0
Improve the Level of Trust of Public Safety Officials through a Commitment to Transparency	3	0
Increase the variety of transportation choices available to Durham residents, in order to improve the access to and mobility of Durham Neighborhoods	7	8
Promote Collaboration among Departments to Deliver Outstanding Service to both Internal and External Customers	5	0
Promote increased access to a diversity of housing options that are safe and affordable	8	3
Promote Long-Term Financial Stability	3	0
Protect natural resources by limiting the environmental impact of city operations and fostering community partnerships	5	0
Provide comprehensive planning processes for future infrastructure needs	4	0
Reduce the Occurrence and Severity of Crime	5	0
Talent Development and Recruitment	4	0
Grand Total	**83**	

Figure 2: Comparison of Durham's current growth plan (2012-2020) and 10 smart growth principles (0 means not related, refer to Appendix A for list of Smart Growth Principles)

jority of its planning initiatives were only recently carried out, we expect the development index not to change significantly within this time period. In the case that the index does alter considerably, we attribute such change to the success of the city's planning initiatives, assuming external factors have little impact on its level of success.

After a thorough research on both the city's website and federal data sources, we were able to collect time-series data for fifteen indicators in the period between 2011 and 2015. As a result, we selected household median income, urban unemployment rate, and job growth rate as economic indi-

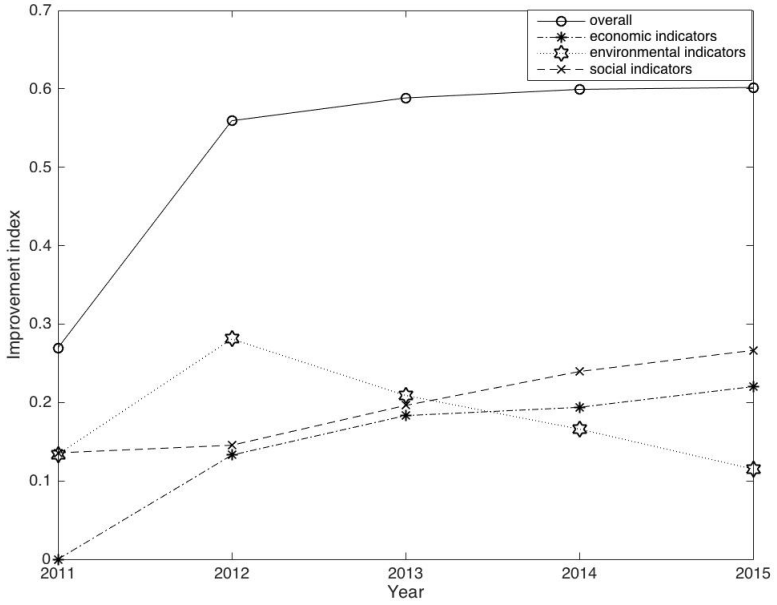

Figure 3: Durham's development index (2011-2015)

cators. For environmental indicators, we used energy intensity[3], air quality index, sewer spills and overflows quantity, urban density, water efficiency[4], carbon dioxide emission. Lastly, for the social indicators, we used health care insurance coverage, crime rate, affordable housing index[5], estimate of housing units, GINI income inequality index, and access to transportation[6]. The specifics of these indicators can be found in Appendix F.

As shown in Figure 2, the development index shows a gradually increasing trend for Durham's economic and social indicators[7]. In 2012, the city experienced a hike in its environmental index, which we attributed to a less than usual amount of sewage spills. This contrast in success among the three categories seems to align with our research, which indicates Durham's strong focus on economic development and social protection.

[3]energy consumed per economic output

[4]water quantity supplied per economic output

[5]house price per household income

[6]percentage of residents within a quarter mile of public transport services

[7]Due to a lack of time and resources, we included only 15 indicators from the main list; indicator data is available in the Appendix.

While Durham has demonstrated propitious progress in some areas of sustainable development, we assess that the city's budget can still be more effectively allocated to urban planning initiatives in order to meet its growth need. Section 4.3 provides a redesigned growth plan for Durham from a simulation run of model 2.

4.3 Redesign for Durham

We used budget data from Durham's Capital Improvement Program[8] to estimate the city's budget limit (US$100.57 million). As mentioned above, in our first simulation run we only included the eight sample smart growth initiatives. In the subsequent run, we incorporated four of Durham's current growth initiatives and eight sample initiatives. Figure 4 and 5 summarizes our test results.

	Initiative	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12
	Budget (US$)	58.22	16.79	14.86	13.86	30.59	45.26	24.69	2	61.69	6.58	4.72	42.17
	Potential Index	0.62	0.16	0.49	0.07	0.5	1.37	0.69	0.12	2.31	0.47	0.38	1.29
Exclusive	Optimal Plan	1	0	1	0	0	0	1	1	N/A	N/A	N/A	N/A
	Ranking	3	6	5	7	4	1	2	8	N/A	N/A	N/A	N/A
Inclusive	Optimal Plan	0	0	0	0	0	0	1	1	1	1	1	0
	Ranking	5	10	7	11	6	2	4	12	1	8	9	3

Figure 4: Results of model 2 simulation for the City of Durham (refer to Appendix D for detailed results)

Results

It is necessary to note that the sample initiatives cannot be applied to Durham without being deliberately altered to suit the city's specific needs. In the first simulation, our results indicated that four sample smart growth initiatives could be potentially beneficial for Durham, including (1) revitalizing public housing sites into mixed-income urban community, (2) building affordable housing units, (3) investing on streets and sidewalks to support public transportation and (4) using lottery proceeds to fund park and conservation efforts.

In the second simulation, our model selected two sample initiatives and three among four current initiatives chosen for analysis. The selected cur-

[8]CIP is a local government's program intended for the city of Durham's growth initiatives, https://durhamnc.gov/DocumentCenter/View/766

Plan	Initiative	Rank within considered set
Exclusive Plan	Revitalize public housing site into a true mixed-income urban community	3
	Build inter-municipal affordable housing that connect adjacent neighborhoods	5
	Investments in streets, sidewalks, and intersection improvements to support public transportation	2
	Use lottery proceeds to fund park and conservation programs	8
Inclusive Plan	Investments in streets, sidewalks, and intersection improvements to support public transportation	4
	Use lottery proceeds to fund park and conservation programs	12
	Reduce Occurence and Severity of Crime	1
	Exeptional Diverse and Healthy workforce	8
	Foster a Culture of Innovation to promote operational efficiency	9

Figure 5: Our result in details

rent initiatives are: (1) reducing occurrence and severity of crime, (2) promoting diverse workforce and (3) fostering a culture of innovation to promote operational efficiency.

Analysis

For simulating purposes, we only selected four of Durham's current initiatives; yet simulation results have clearly aligned with our expectations and manifested many of our model strengths:

1. Our results show that all the environmental initiatives were disregarded in both optimal plan selections. This is fundamentally intuitive as past data indicates that environmental sustainability is not one of the city's immediate concerns.

2. Simulation results also provide exciting perspectives into the interaction among different initiatives and how compromises in decision making are necessary when constraints are present.

3. The optimal plan does not strictly follow the potential ranking because of two reasons. First, ranking index is calculated individually while the optimal plan picks the best combination. Secondly, while individual potential takes into account the (cost/time) ratio, the optimal planning solution only considers the total amount of effect regardless of the time required. This point would also apply to the case study for Liverpool below.

5 Case study: Liverpool, England

5.1 Current growth plan

Liverpool, in North West England, is a metropolitan area with an estimated population of 478,580 in 2015. It is also a major port city with a diverse population. Its economy is one of the largest within the United Kingdom, with GDP per capita estimated to be $32,121 in 2014. As with many British cities, Liverpool has experienced a decline in population since 1930 [7].

It is important to understand that Liverpool, with more than 800 years of history, must experience a vastly different set of issues from Durham, a relatively young city. We have chosen Liverpool so that a meaningful comparison of growth initiatives between two equally dynamic cities can be attained.

Furthermore, Liverpool's local government has seen a 58% cut to its government funding since 2010, thus any planning decision needs to be prudent [8]. The city's extremely tight budget makes a strong case for the usefulness of our second model.

Even though we hope to find Liverpool's long-term growth plan, only documentation of its 2016/17 budget allocation was available on the city's website. Thus, while the information is useful for our reassessment of Liverpool's future growth plan using model 2, it limits the extent to which we can reliably examine its current plan's success, a process based on past data. We would only therefore assume that the city's policy direction remained relatively unchanged over the past few years.

As shown in Figure 4, the city has four improvement programs that correspond to three of the smart growth principles.Specifically, Liverpool aims to better the living conditions and economy of its existing communities by investing in regeneration projects such as the St Johns Market Refurbishment and Stanley Park Car Park Improvement [8]. With the reconstruction of the Stonebridge Crossroad site, the city council hopes to attract more businesses as means to provide much-needed job opportunities for the local community[9].

In addition, the city invests in promoting the sense of attractive communities by building recreational park grounds and playing fields. Enhancement to the Croxteth Hall is part of a series of projects to reinforce the identity of a historic city. Lastly, Liverpool directs much of its budget in generating more housing units to accommodate the needs of a very dense

[9] http://www.liverpoolecho.co.uk/news/liverpool-news/next-stage-stonebridge-cross-rebirth-10567769

Initiatives	Smart Growth Principle	Budget (pounds)
Improve road conditions and street lighting	0	54,926,633
Regeneration development of major infrastructures and buildings	7	22,305,832
Improvement grants for disabled	0	3,491,000
Allocate fundings to schools' investment programs	0	30,768,339
Build recreational grounds and playing fields for leasure activities	5	1,825,014
Improve and enhance Croxteth Hall	5	897,063
Build new housing units and bring voids back into use	3	10,435,788
Roll out corporate initiatives such as Network Technology Refresh	0	5,476,000
	Total	130,125,669

Source: http://liverpool.gov.uk/media/8638/budget-book-2016-17.pdf

Figure 6: Comparison of Liverpool's current growth plan (2016-2017) and 10 principles of smart growth [8]

population (its urban density is about five times that of Durham[10]). The city's plans to secure and utilize voids will address the lack of space for new housing projects.

Even though the projects mentioned above accords with some smart growth principles, Liverpool's priority lies largely in maintaining public roads and infrastructures, most of which were built long ago and have been running down over the years. Efforts in this area, along with funding to extend school capacities, respond directly to the population growing again in the recent years. However, this approach may only serve as temporary measure, and the city may need an overarching strategy for the many complex challenges to come from urbanization in the future.

5.2 Evaluation of the current plan

For Liverpool, we were able to collect data for only eight indicators. The economic indicators chosen are gross disposable household income per head, job growth rate, and urban unemployment rate. The environmental indicators are hourly mean air quality index, urban density, and carbon dioxide emission per capita. The social indicators are total number of recorded crimes and house price index. Even though the specifics of some of these indicators are slightly different from those we used for Durham (see Appendix B,E,F), they all reflect the same components of the sustainability pillars from Table 1.

As shown in figure 5, the development index shows fluctuating trends for the three indicator categories. The economic trend experienced a trough

[10]see Appendix B,E

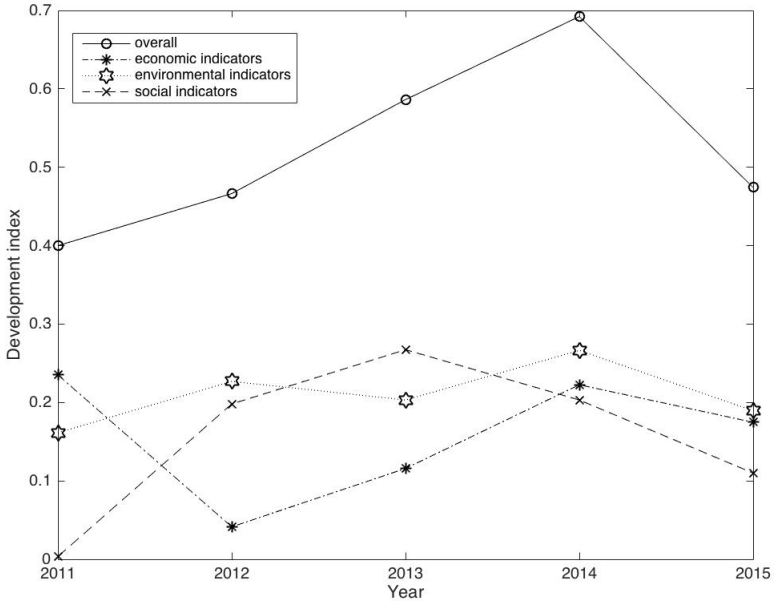

Figure 7: Liverpool's development index (2011-2015)

in 2012 when the city experienced a negative job growth and the highest unemployment rates in the five-year period. The economy picked up afterwards but ended at a lower growth level than in 2011. Meanwhile, the social indicators reached their peak in 2013, but declined since then. The environmental category had a stable standing compared to the other two with no extreme downfall or uprising.

The changes in the indexes seem to be consistent with the current initiatives of the city. The improvement in the economic trend might stem from the city's corporate initiatives as well as renovation projects of potential industrial sites similar to Stonebridge Crossroad. Liverpool's various housing projects and infrastructure upgrades to accommodate population growth might account for the peak in the social indicators and reduction in pressure on the environment. However, these measures are shown to be temporarily effective as the city was approaching its capacity, which is signified by the overall development drop at the end of the time period in the graph.

5.3 Redesign for Liverpool

We obtained Liverpool's budget data from its Budget Book 2016/17[8]. We ran the two simulations on Liverpool as previously done on Durham. Figure 8 and 9 summarizes our simulations' results. The specifics of the initiatives are also tailored to the city's characteristics.

Results

Plan	Initiative	Rank within considered set
Exclusive Plan	Revitalize mid-rise public housing site into a true mixed-income urban community	3
	Build inter-municipal affordable housing that connect adjacent neighborhoods	5
	Investments in streets, sidewalks, and intersection improvements to support public transportation	2
Inclusive Plan	Build Inter-municipal affordable housing that connect adjacent neighborhoods	6
	Loans to build affordable housing for low-income families near transportation area	5
	Investments in streets, sidewalks, and intersection improvements to support public transportation	2
	Use lottery proceeds to fund park and conservation programs	8
	Allocate fundings to schools' investment programs	3

Figure 8: Results of model 2 simulation for Liverpool (refer to Appendix G for detailed results)

Liverpool	Initiative	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12
	Budget (US$)	93.41	26.95	23.84	22.23	49.08	72.63	39.62	6.80	68.11	4.33	38.15	6.79
	Potential Index	1.85	0.24	1.58	0.1	1.62	3.46	2.36	0.9	1.52	0.48	1.89	0.76
Exclusive	Optimal Plan	1	0	1	0	0	0	1	0	N/A	N/A	N/A	N/A
	Ranking	3	7	5	8	4	1	2	6	N/A	N/A	N/A	N/A
Inclusive	Optimal Plan	0	0	1	0	1	0	1	1	0	0	1	0
	Ranking	4	11	6	12	5	1	2	8	7	10	3	9

Figure 9: Our result in details

In the first simulation, our results indicated that three sample smart growth initiatives could be potentially beneficial for Liverpool, including (1) revitalizing mid-rise public housing sites into mixed-income urban community, (2) build inter-municipal affordable housing that connect adjacent neighborhoods, and (3) investments in streets, sidewalks, and intersection improvements to support public transportation.

In the second simulation, our model selected four sample initiatives and one among the four current initiatives chosen for analysis. The selected current initiative is allocate funding to schools' investment programs.

Analysis

1. Both optimal plans agree that Liverpool should prioritize initiatives that improve public infrastructures,transportation, and housing. In fact, the city is on that track as it will dedicate the majority of its budget in these areas (refer to Figure 6).

2. Even though the exclusive plan suggests a need for converting mid-rise housing sites into mixed-income communities, the inclusive optimal plan rules them out and instead suggests a loan program to build affordable housings for low-income families near transportation areas. In addition, the city should create a lottery program to generate funding for parks and recreation projects. However, the city should maintain its current initiative to invest in schools.

3. The difference in the optimal plans from the two simulations suggests that smart growth may not strictly be the best design. Rather, a combination of smart growth initiatives and the city's current initiatives are required to work out the customized needs of a population.

5.4 Compare initiatives and rankings between the two cities

As mentioned in previous sections, the matrix of impact coefficient in model 2 requires intensive research and understanding of each city's characteristics. This limits our ability to provide an accurate comparison between the two growth plan designs. However, we noticed that Durham is capable of implementing more initiatives due to its larger budget in relation to population size.

Furthermore, we found that it is optimal for Liverpool to include more researched smart growth initiatives, as compared to Durham. Three of four Durham's current initiatives included were advised to keep. This is no indication of which city has a better current plan rather than a realization that our list of sample initiatives were limited to only U.S. cities.

6 Analysis - Sensitivity and Scalability

6.1 Data accuracy and availability are crucial

As said throughout this paper, our two main models depend entirely on the accuracy and availability of indicator data. For instance, missing data

can affect the simulation results and so alter our interpretations. In addition, the longer the time period for which we can collect data is, the more accurately our development indexes reflect the success of the city design.

6.2 Sensitivity

Our model is sensitive to the construction of the indicator matrix A in the second model. Even with thorough research, our opinion is subjective and biased. In the next step, we hope to construct the matrix in a relative scale.

6.3 Scalability

While data collection was time consuming, all computations can be done easily. In our simulation, we used Excel's function and Solver to get solutions for both models (to include more variables, we recommend using Matlab built-in function). Therefore, our model can be implemented efficiently and easily even on a big data set. We are also confident that if a large standardized set of indicators and initiatives can be found for all cities, our models will be able compare them better.

Again, our model provides flexibility in deciding the input parameters, i.e indicators, initiatives, available budget etc. It has great potential to be combined with other predictive models. For instance, one may be able to predict the trend of a city's development indexes in the upcoming years.

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