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Team Control Number

72295

Problem Chosen

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2017
MCM/ICM
Summary Sheet

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To analyze the growth plans of th ecities of Oakland and Cardiff, we began by choosing three mathematical metrics to measure how "smart" their growth was. We defined each city growth plan with four numbers; one for compact building design, one for preservation of green space, one for transit accessibility, and one for the development of existing communities. We then combined these to form a single numeric metric for both cities' growth plans.

Oakland's plan was subpar; the city growth thus far was reasonably smart, but they lacked acceptable coverage of public transportation, so their plan should have included the construction of new bus stops and train stations as the first priority. Oakland does not currently plan to build any new bus stops or train stations, though. Furthermore, while Oakland's population density is decent, it clearly has much room for improvement when compared to cities like Macau. To encourage the city to grow more smartly, we recommend a new growth plan that includes the construction of new bus stops and train stations and the constrution of more compact public spaces and residential complexes. These plans will help Oakland reduce its physical and carbon footprints, especially if the population of the city increases in the near future.

The growth plan of Cardiff suggests that the city will focus on 8 strategic sites. With the smart growth metric, we analyzed the compact building design and transportation accessibility of these new sites as well as their impact on the existing communities around them. Cardiff government has put effort on the preservation of green space and made the city more walkable and accessible, but its population distribution around the city created a hollowing effect in the city center and discouraged mixed land uses in these area. Based on the statistical data, we eventually landed on these areas our solutions that foster attractive and compact neighborhoods and shorten travel time for the citizen of Cardiff.

ICM 2017 Problem E

Team 72295

January 2017

1 Background

The two cities we chose, Oakland and Cardiff, were selected because they met the population criteria, had different and intriguing histories, and published many useful data regarding land use, transportation, and demographics. Oakland is a city located near San Francisco in California. Founded in 1852, it now has a population of about 400,000.[10] Cardiff is situated on the north side of the Bristol Channel on Great Britain, and is the capital city of Wales. Having been founded thousands of years ago, it now contains 340,000 people.[10]

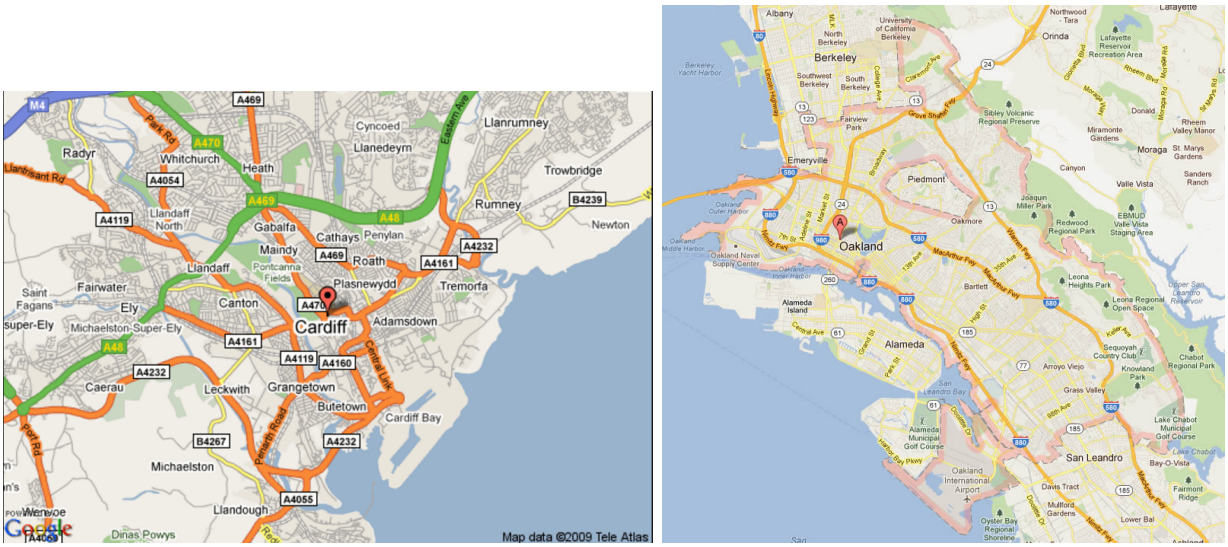

Figure 1: The cities of Oakland, USA and Cardiff, Wales. [13]

2 Smart Growth Metrics

The quantitative metric we chose was an aggregation of four metrics, each specifically measuring one or more of the ten principles of smart growth, as enumerated by the Environmental Protection Agency.

2.1 Individual Metrics of Smart Growth Principles

2.1.1 Compact Building Design

The first metric is the simplest; it measures how compactly people, and by extension buildings, are packed in the city, thus measuring a city's compact building design. The number is simply the average population density of the city:

$$H_1 = \frac{p}{A} \tag{1}$$

where p is the number of people in the city and A is the area of the city.

2.1.2 Preservation of Green Space

The second metric is also quite simple. It deals with the preservation of green space. The equation is

$$H_2 = \frac{A_G}{A} \tag{2}$$

where A_G is the total area of the city comprising parks, agriculture, and fields.

2.1.3 Transit Accessibility

The third metric is highest for cities with a variety of well-placed transportation options, including walking. This metric is calculated by dividing the city up in a grid. Each tile is assigned points based on how accessible it is (i.e. how many transportation options residents have). A tile gains one point for having a nearby bus stop and one point for a nearby train station, and one point for an industrial/commercial building (indicating that residents can get around by walking). The metric for the entire city is

$$H_3 = \frac{\sum_{i=0}^{n} A_i x_i}{A} \tag{3}$$

where A_i and x_i are the area and accessibility score, respectively, of a single tile, and A is the total area. This metric represents the average ability of a city resident to get around using public transit or walking.

2.1.4 Developing Existing Communities

Finally, we consider whether the city is developing existing communities or building new ones. For this, we need only look at the city's development plan. The final smart growth metric for a city is

$$H_4 = \frac{n_R}{n} \tag{4}$$

where n now represents the total number of projects currently planned by the city and n_R represents the number of those that are in residential areas, as opposed to industrial/commercial or undeveloped areas.

2.2 Aggregate Metric

In computing the aggregate metric, we made the assumption that each individual metric would be given equal weight. We decided to make each individual metric a value between 0 - 1, 0 indicating the minimum score in this area, while 1 indicating a maximum score. We average over the 4 metrics, producing a single floating number between 0-1. The strategies to transform the metrics to a normalized score are discussed below.

2.2.1 Compact Building Design

As a reminder, we are using population density as a proxy metric for compact building design. In order to transform a continuous, unbounded quantity like population density to a normalized 0 - 1 scale, we defined a sensible maximum bound for population density.

We set the maximum population density to 21,000 persons / km^2, based on the current population density of the city of Macau. According to [10], Macau is a city that has a population of 643,000, which makes it a comparable mid-sized city. We are asserting that a growth plan that can achieve this maximal population density has achieved the highest score for compact building design. We acknowledge that this is a simplification, as citizens in the US or UK might not be comfortable with the high population density of an Asian city like Macau. However, this is a maximal value worth aiming for in a growth plan, especially if cities have to account for close to 50% population growth by 2050.

2.2.2 Preservation of Green Space

If a city can preserve all their current green space, they receive the maximal score of 1. If the growth plan calls for eliminating green space that amounts to some X % of the area of their city, their score will be defined as (100 - X) %.

2.2.3 Transit Accessibility

Metric H_3 transforms directly to a normalized 0 - 1 scale. If X% of the developed area will include accessible public transportation, the score will be X %.

2.2.4 Developing Existing Communities

Metric H_4 translates directly to a normalized 0 - 1 scale. If X % of development projects are working on existing communities, the score with by X %

3 Current growth plans

3.1 Oakland

Oakland's current growth plan comprises several projects to develop downtown, residential areas, and areas that have not yet been developed.[4] The vast majority of these projects involve renovating or replacing existing buildings and streets. Given that the city has not made any significant zoning policy changes recently, none of our smart growth metrics are

projected to change in the near future for Oakland unless they adopt a more diverse or more ambitious growth plan.

3.1.1 Compact Building Design

Of Oakland's planned construction projects, many of them are the rennovation of old buildings or the enhancement of street space, not building new buildings or complexes.[4] Therefore, the best way to evaluate compact building design as expressed by Oakland's growth plan is to look at how many people it currently houses in the area it has. Oakland has 406,000 residents[5] living in $202\,\mathrm{km}^2$,[10] giving it a population density of $2010\,{}^{\mathrm{ppl}}/_{\mathrm{km}^2}$. This is a decent density for its size, but it could certainly fit more people with more urban infrastructure. Given that the total population of Oakland has not changed much in the last few decades,[5] it is reasonable to assume that this density will remain roughly the same into the future. The City of Oakland does seem to understand the need for a more compact city, though, as most of its currently planned construction projects are rennovations of existing spaces to give them more uses and capacities in the same amount of space.[4]

3.1.2 Green Space

Of those $202\,\mathrm{km}^2$, 6.64% of it is park or undeveloped space.[2] This is an acceptable ratio for a city; any more green space and it would take up more space, developing more land and increasing travel distances. Any less and people in the city would have to drive to parks and forests, and the city itself would become impermeable. Furthermore, none of Oakland's planned projects will remove any green space.[4] Oakland currently has several planned projects to enhance its streets to create more green space without taking up very much room,[4] so the green space to building ratio will only improve in the future.

3.1.3 Transit Accessibility

To analyze Oakland's transit accessibility, we used a digital map of Oakland with its bus routes and train lines[11] to compute the H_3 metric with each tile being one pixel. We defined "nearby" for Oakland as walking-distance, which we arbitrarily set to be 0.5 km. The results of our calculation are visible in Figure 2 on the following page. 31% of Oakland is within 0.5 km of a bus stop, and 4.0% of Oakland is within walking distance of a train station, creating a total H_3 metric of 35%. These numbers are abysmal. Considering that Oakland is not currently planning to build any new stops or stations,[4] public transportation in the city is and will remain inaccessible without driving for the vast majority of people.

3.1.4 Developing Existing Communities

Despite severely lacking coverage of public transit, the City of Oakland *does* understand the importance of developing existing communities, as 43 out of 45, or 95.6%, of Oakland's current projects are enhancing, upgrading, and remodelling features of existing communities rather than building new ones.[4]

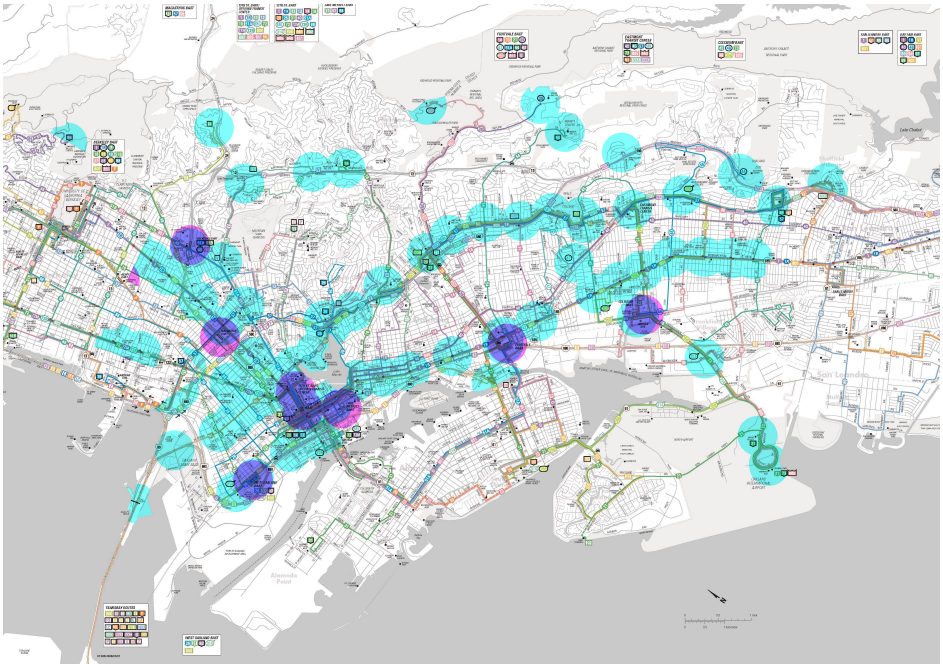

Figure 2: The City of Oakland, color-coded where cyan regions are near a bus stop, magenta regions are near a train station, and blue stations are near both.[11]

3.1.5 Aggregate Metric

The individual metrics computed for Oakland are shown below:

1. **2010** persons / km^2 will be population density based on the current plan
2. **0 %** of Oakland's land area will be considered lost green space according to the current plan.
3. **35%** of the developed area will be within 0.5 km walking distance of accessible public transportation options, including bus or rail.
4. **95.6%** of development projects are working on existing communities rather than building new ones.

The individual normalized metrics computed for Oakland are as follows:

1. **9.5 %** $= \frac{2010}{21000}$ persons / km^2
2. **100 %** = (100 - 2.5) %
3. **35 %** of developed land is transit accessible.
4. **95.6 %** of developed land is building existing communities.

Thus the final metric for the current Oakland growth plan is **60.0 %**.

3.2 Cardiff

The Cardiff Local Development Plan identifies several large areas for future development. The development of these strategic sites will have an impact on the the existing communities and services and create needs for additional infrastructures.

Cardiff plans to make housing and employment provision in 8 strategic sites, marked in Figure 3.

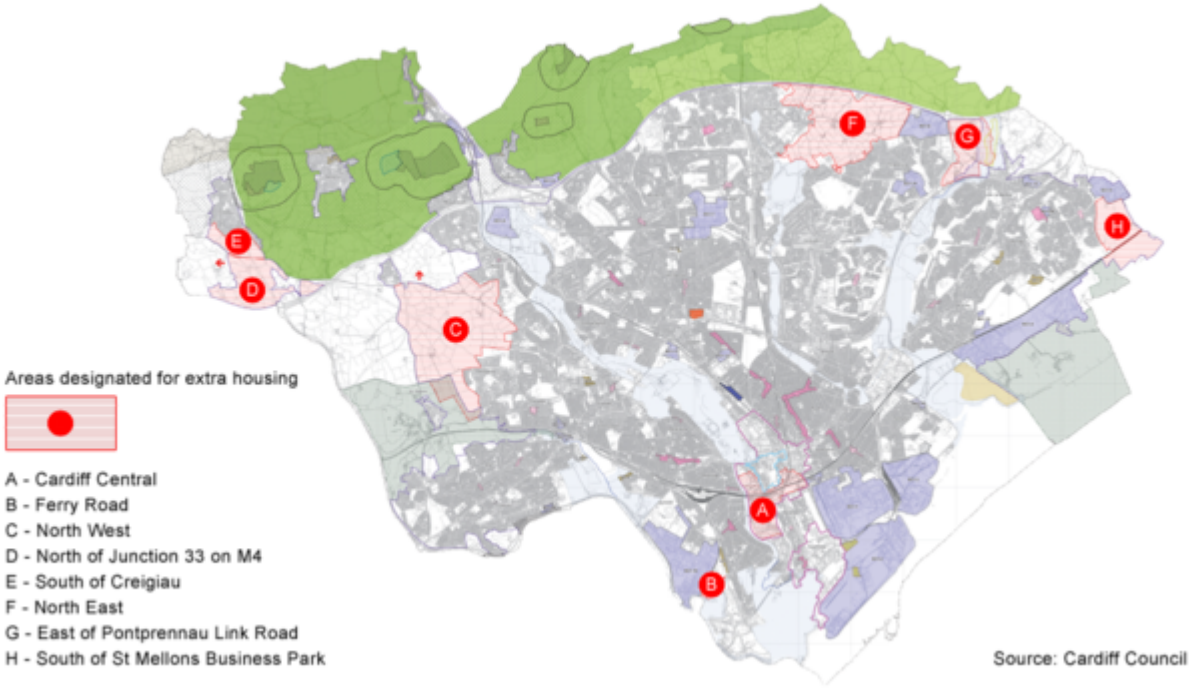

Figure 3: Cardiff Long Term Development Plan Strategic Sites[8]

3.2.1 Compact Building Design

For sites A - H, the plan provisions for a certain number of houses to be built.[6] To evaluate the metric for compact building design, we compute the density of homes to be built in these sites.

A 2531 homes/ km^2 = 2000 homes / 0.79 km^2

B 5000 homes/ km^2 = 500 homes / 0.10 km^2

C 1397 homes/ km^2 = 5000 homes / 3.58 km^2

D 1834 home/ km^2 = 2000 homes / 1.09 km^2

E 1625 homes/ km^2 = 650 homes/ 0.4 km^2

F 1844 homes/ km^2 = 4500 homes / 2.44 km^2

G 1585 homes/ km^2 = 1300 homes / 0.82 km^2

H 0 homes/ km^2 = 0 homes / 1.05 km^2

Since area H has no homes being developed, but instead will be used to build a business park to accomodate for new employment opportunities, we ignore this area in our average building density estimate. The average building density over sites A - G is 2259 homes / km^2. According to the 2011 UK census, the average household size in the UK was 2.3 people per household; thus, the population density over these strategic sites was 5195 persons / km^2.

3.2.2 Preservation of Green space

The LDP describes that 35% of new developments will happen on Greenfields, while 65% of houses under the plan will be built on existing Brownfields.[6] Strategic sites took up about 10 km^2, so 3.5 km^2 of Greenfield is lost in development. Cardiff is loosing 3.5 km^2 of green space to its total 140.3 km^2 of city area, or **2.5%** of the total area will become lost green space according to the current plan.

3.2.3 Transit Accessibility

To analyse the public transportation development in Cardiff, we first overlay the strategic site map with the current bus route map.

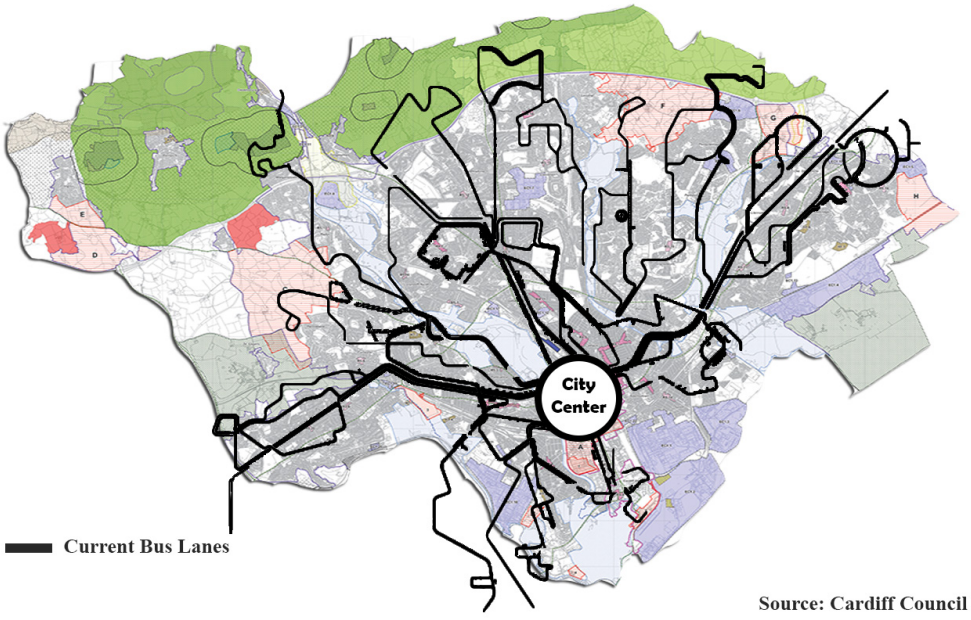

Figure 4: Cardiff Strategic Sites map with current bus routes[9]

From the map we can tell that the strategic sites located close to the city center are adjacent to existing bus routes and don't require extra transportation supports. But some of the sites at the outer rim of the city are barely reachable through the current public transportation system. The Cardiff Local Development Plan has therefore established plans

of Rapid Transit serving northwest and northeast Cardiff. Walking, cycling and railroad improvements are also included in the plan and will provide residents with more travelling choices.[6]

By looking at the strategic sites that have public transit lines, and estimating areas 0.5 km away from current transit routes, we found that **45%** of the developed area will have accessible transportation options.

3.2.4 Developing Existing Communities

All 8 strategic development sites in Cardiff are adjacent to existing population areas, defined by having at least a "low population density" according to Figure 5. However, only site A) Cardiff Central and site C) North West actually overlap with existing population areas. 2 of the 8 strategic sites, or 25% of development projects, are enhancing housing opportunities in existing communities rather than building new ones.

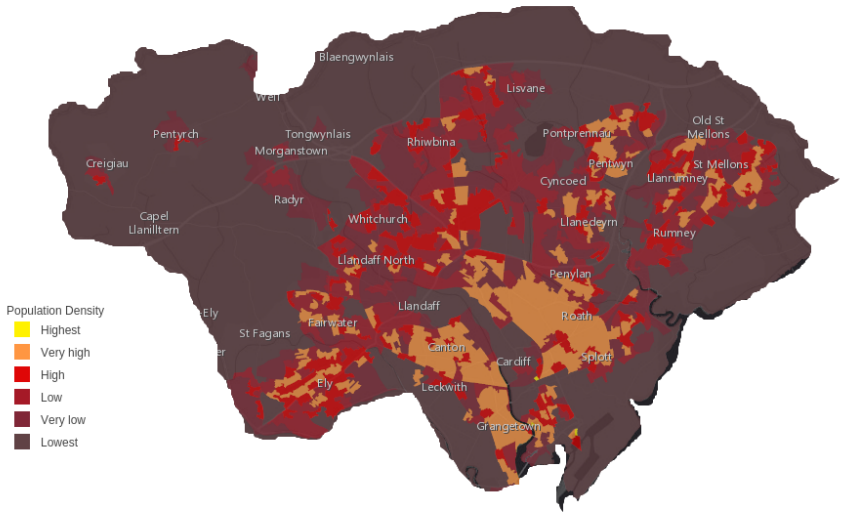

Figure 5: Population Density of Cardiff[7]

3.2.5 Aggregate Metric

The individual metrics computed for Cardiff are shown below:

1. **5195** persons / km^2 will be population density over the strategic areas based on the housing provisions set out by the plan.
2. **2.5%** of Cardiffs land area will be considered lost green space according to the current plan.

3. **45%** of the developed area will be within 0.5 km of accessible public transportation options.
4. **25%** of development projects are working on existing communities rather than building new ones.

The individual normalized metrics computed for Cardiff are as follows:

1. **24.7 %** $= \frac{5195}{21000}$ persons / km^2
2. **97.5 %** = (100 - 2.5) %
3. **45 %** of developed land is transit accessible.
4. **25 %** of developed land is building existing communities.

Thus the final metric for the current Cardiff growth plan is **48.05 %**.

4 New growth plans

4.1 Increased Public Transportation

The first method of improving city growth into the future is the addition of bus stops and train stations. Because the purpose of public transit, from a smart growth perspective, is to allow citizens to traverse the city without driving, transit is only effective if it is accessible by walking from a point of origin. Common sense says that the average person will walk no farther than 0.5 km to get to a bus stop or train station, so these features should be built in strategic locations such that at least one public transit center is within 0.5 km of any point in the city, or at least most points.

The addition of bus stops and train stations will do wonders for smart growth if placed in areas not currently served by public transportation. Most of Oakland falls into this category, so new access to public transit is imperative to Oakland. Because a single stop will serve a circle of radius 0.5 km regardless of population, once enough stations exist in the city, they will remain effective regardless of how the city's population grows (though some might need to be remodelled to account for higher traffic). In terms of Cardiff, there are enough bus stations covering all the existing populated districts, but the problem is that all the bus routes go to the city center eventually, making it inefficient for people to transit outside the city center and causing traffic jams during rush hours. The solution we propose is adding extra bus routes circling the city center and create new transit centers to reduce travel time.

4.2 Encourage Compact Building Design

Based on the current population density (Oakland: $2010\,^{\text{ppl}}/_{\text{km}^2}$ and Cardiff: $5195\,^{\text{ppl}}/_{\text{km}^2}$), we believe that the cities can still have the potential for more compact communities because other cities like Macau with similar population scales (566,375 ppl[10]) have much higher density($21,340\,^{\text{ppl}}/_{\text{km}^2}$. Compact building design can increase the mixed land use of the city

and allow city districts to become more walkable. With more walkable city districts, people are able to traverse in the city freely and communicate with their neighbors. This, in turn, helps foster friendly and attractive communities where the residents feel a strong sense of belonging. Compact building design also allows the city to save more place for the future population growth. If the population of Cardiff and Oakland will increase by an additional 50%, both cities will have the enough extra residence sites and transportation means to support the population increase.

4.3 Metric according to new plan

If we only increased public transportation access to 66 % in both cities

- Oakland's aggregate score would be **67.7 %**
- Cardiff's aggregate score would be **53.3 %**

If we only increased the compact building design so that population density achieved $10,500^{\text{ppl}}/_{\text{km}^2}$, or 50 % of the $21,000^{\text{ppl}}/_{\text{km}^2}$ of Macau,

- Oakland's aggregate score would be **70.2 %**
- Cardiff's aggregate score would be **54.4 %**

If we implemented both these measures simultaneously,

- Oakland's aggregate score would be **77.9 %**
- Cardiff's aggregate score would be **59.4 %**

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