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Finding an Effective Sustainable Model for a Wireless Metropolitan-Area Network: Analyzing the Case of Pittsburgh

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Finding an Effective Sustainable Model for a Wireless Metropolitan-Area Network: Analyzing the Case of Pittsburgh[1]

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Abstract

Many cities are seeking ways to facilitate the deployment of a wireless metropolitan-area network (WiMAN) based on wifi technology. City leaders must often balance competing goals, including the desire to maximize the area in which wireless services will be available, to maximize competition among providers, to minimize subsidies from government agencies and non-profit organizations, and to ensure financial sustainability. This paper investigates the extent to which these goals can be met with four basic models: one citywide monopoly WiMAN provider, facilities-based competition from multiple citywide WiMAN providers, one citywide WiMAN offering wholesale services to competing retail service providers, and open competition where multiple providers are free to serve only the more profitable neighborhoods. We estimate costs for constructing and operating a WiMAN in Pittsburgh using a sample architecture. We develop a regression model to roughly predict subscription rates and revenues based on city demographics, and apply that model to Pittsburgh, Philadelphia, and Minneapolis. Using these rough estimates, we analyze the extent to which competition can be sustained and service can be provided citywide under different models, and with different forms of intervention. The interventions analyzed include providing one-time or annual subsidies (from government or non-profit foundations), guaranteeing that city government will be a large customer, advertising wireless services, and facilitating access to locations that are suitable for antenna placement. For Pittsburgh, we conclude that citywide facilities-based competition is not financially sustainable. Citywide monopoly operation and citywide competition at the retail level are almost equally viable financially, and both appear sustainable, but financial failure is within our margin of error. Moreover, we show that retail competition can only survive if the City has leverage to prevent the monopoly wholesaler from raising prices to the level that maximizes the wholesaler's profit, as this will end competition. Finally, the City or a powerful third party must provide some form of inducement such as becoming an anchor customer to motivate providers to serve all parts of the city. Otherwise, providers will maximize profit by focusing on high-income neighborhoods, leaving much of the city unserved.

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[1] This paper is based on research performed at Carnegie Mellon Univ. for the Pittsburgh City Council. Results were formally presented in a Pittsburgh City Council hearing.

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1 Introduction

As wireless technologies become increasingly ubiquitous, city governments, businesses, and non-profit organizations in cities across the country are taking an interest in creating wireless metropolitan area networks (WiMANs). While such a network may have many benefits for citizens, local businesses, and municipal operations, costs can be considerable. Cities have adopted a wide variety of policy approaches to cover costs and maximize benefits. The long-term financial outlook for a WiMAN and the extent to which it meets the needs of users depend heavily on the decisions of policy-makers and the roles played by government agencies, commercial companies, and any participating non-profit organizations. This paper analyzes the impact of various policies and financial models.

In this paper, we use Pittsburgh, PA as a case study for assessing the financial prospects of building a WiMAN and draw conclusions that may prove useful to other cities. This paper provides an example of estimating revenues and costs associated with such a network in Pittsburgh. These estimates serve as a basis to analyze four financial models that a city could employ in creating a WiMAN. These four models represent various ways in which the entities involved in creating and operating a WiMAN could be organized. The models we consider are: 1) one citywide monopoly WiMAN provider; 2) facilities-based competition from multiple citywide WiMAN providers; 3) one citywide WiMAN offering wholesale services to competing retail service providers; and 4) open competition where multiple providers are free to serve only the more profitable neighborhoods. In general, the roles of vertically integrated provider, wholesaler, and retailer in these four models may be played by city government, commercial companies, or non-profit organizations.

Each model is assessed based on it's effectiveness in achieving four objectives: 1) to maximize the area in which connectivity is available; 2) to maximize competition in the market, with the goal of achieving better prices and service for users; 3) to minimize subsidies needed to build the network, and 4) to ensure the financial sustainability of the network, which is to ensure that the revenues generated by the network will exceed the cost of building and maintaining the network with a rate of return that is acceptable to the entity or entities participating in the project. Not all of these objectives will be applicable to every WiMAN project, but they constitute a baseline for analyzing each model. There are also certain tradeoffs between these four objectives that we will examine. We also discuss a number of policy levers, which local decision-makers may use to accomplish their goals. Where the financial effect of these levers is quantifiable, we assess their effectiveness in supporting the sustainability of the WiMAN.

The rest of the paper is organized as follows. In section 2, we describe in more depth the models considered in this study. Section 3 presents a discussion of possible policy levers. Sections 4 and 5 describe the estimation of revenue and cost, respectively. In section 6, we quantitatively assess each model's ability to be financially sustainable, support competition, and provide services citywide. This assessment builds on the cost and revenue estimates of Sections 4 and 5, and considers the impact of policy levers from Section 3. The paper is concluded in Section 7.

2 Description of WiMAN Models

There are several ways to categorize WiMAN policies into distinct models [1, 2, 3, 4]. For the purposes of this paper, a model is considered to be the economic or business organization of various entities involved in building and operating a WiMAN. This paper considers four WiMAN models: one vertically-integrated citywide monopoly, facilities-based competition, one citywide WiMAN offering wholesale services to competing retail service providers, and open competition where multiple vertically-integrated providers are free to serve only the more profitable neighborhoods. Under the models presented in this paper, a government agency, a private corporation, or a non-profit organization may assume the role of operator offering wholesale service, retail service, or both. The requirements for return on investment and profitability may change depending on which type of entity fulfills each of these roles. For example, commercial companies demand a profit commensurate with risk, while government agencies seek irrefutable value for any taxpayer dollars spent. Regardless of who plays these roles, the organizational model remains essentially the same.

- **Monopoly:** In a monopoly model, one citywide monopoly WiMAN provider owns the network, and assumes responsibility for its construction and operation, although it may hire others to fulfill some of these responsibilities. Thus, the monopoly plays both the wholesale and retail roles. For example, Chaska, MN [5] and St. Cloud, FL [6] employ a monopoly model, in which city government owns and operates the WiMAN. Other cities may select one commercial company or non-profit organization to act as a monopoly WiMAN, perhaps by offering exclusive access to light poles and other convenient antenna sites. Municipalities may favor a monopoly model, because it provides ubiquitous coverage and minimizes the cost of deployment and operation, but this model does not provide for competition of any kind.

- **Facilities-based competition:** In a facilities-based competition model, two or more WiMAN providers own and are responsible for operating separate vertically-integrated networks that serve identical or substantially overlapping regions. To the best of our knowledge, no city has employed a duopoly model, possibly because of the high costs of the infrastructure. Municipalities may strive for this model because it allows strong competition, in addition to ubiquitous coverage.

- **Wholesale-retail:** In a wholesale-retail model, one citywide WiMAN offers wholesale services to competing retail service providers. The wholesaler is responsible for building and operating a wireless network that covers the city, and provides services to the customers of all of the retailers. Each retailer must sign up customers, manage accounts, provide customer service, and collect payments. Either the wholesaler provides connectivity between the WiMAN and the rest of the Internet, or each retailer provides this for its own customers. Both the wholesale and the retail roles could be fulfilled by the government, a non-profit organization, or a private company. The wholesaler may or may not offer retail services as well. A number of cities have adopted this model, e.g. [7, 8, 9, 10]. In Philadelphia [9] and San Francisco [8], a commercial company (EarthLink) acts as a wholesaler, and as a retail ISP. In Philadelphia, EarthLink also cooperates with the non-profit Wireless Philadelphia with whom they revenue share [9]. Under the Boston Task Force recommendation, the wholesale provider is a non-profit organization that allows any WISP to offer retail services, but does not offer its own retail services. The wholesale-retail split model may be favored by municipalities because it provides ubiquitous coverage and some degree of competition, without the cost of building entire WiMANs throughout the same area as occurs with facilities-based competition.

- **Open competition:** In an open competition model, vertically integrated ISPs are free to serve only the parts of the city they choose, presumably on the basis of profitability. Cities adopt this model by default, unless they create policies to the contrary. This is the only model addressed in this paper in which the WiMAN does not cover the entire municipality. A WiMAN that provides no service to less profitable areas will generally find it easier to achieve financial sustainability and will have less need for subsidies, but obviously at the cost of ubiquity.

3 Leverage and Policy Levers

Certain policy levers can affect the sustainability and risk associated with each of the models discussed above, and these policy levers can be sources of leverage with which local policy-makers are able to influence the characteristics of a WiMAN that is not city-owned and -operated. This section describes some potential levers that the government and other organizations with significant leverage can implement. In Section 6, we examine the quantitative effect of some policy levers discussed here.

Policy Levers that Affect First-Year Cash Flow

A government, foundation, or other external entity interested in helping a WiMAN could subsidize or reduce build-out costs. This intervention could come in the form of a one-time cash subsidy from city or state funds, a federal grant, or a donation from a charitable foundation. Donated infrastructure, labor, or a reduction in the institutional costs associated with building the WiMAN, such as the cost of any permits needed, would have the same effect.

Conversely, policy mechanisms can increase the initial investment needed. For example, the government can require expensive permits to access property that the WiMAN requires. In effect, this would be a negative subsidy. It is the sum of these actions on first-year cash flow that matters most, and that will be considered in subsequent analysis.

Policy Levers that Affect Annual Cash Flow

A government or other external entity could also take action to improve annual cash flow by reducing annual cost, increasing annual revenue, or both. This type of intervention could come in the form of annual cash subsidies from city or state funds, federal grants, or a charitable organization. Governments could also offer annual rights of way below market price, or conduct education campaigns that advertise WiMAN services, thereby reducing the burden on the service providers.

More indirectly, city governments or other large organizations could act to increase subscription revenue by making a commitment to become a substantial customer of WiMAN services. In our analysis of Pittsburgh, the city government's potential uses of a WiMAN that we identified were not sufficient to generate revenues that could cover a significant portion of annual costs, making city government a poor anchor customer. One problem is that many WiMAN uses for city government require large capital investments. For example, a WiMAN may be useful to connect parking meters to a central server [11, 12], but only if the city can afford to replace its existing parking meters. Nevertheless, city government has proved to be an effective anchor customer in some cities. Public safety applications may someday play an important role, since most of the current public safety communications systems in the US do not support broadband [13]. Also, a city could implement a program to subsidize in part or in whole the accounts of those who would otherwise be unable to afford broadband services, in hopes of narrowing the digital divide.

A WiMAN's annual cash flow could also be negatively affected by the actions of government or an external entity. A government could charge more than the market price for rights of way or leasing properties needed for infrastructure. Levying additional taxes or mandating a profit-sharing agreement are other ways that will have the effect of lowering annual cash flow. EarthLink, the WiMAN wholesaler in Philadelphia, is required to share revenues with the local nonprofit Wireless Philadelphia [9]. As above, it is the sum of these actions on annual cash flow that matters, and will be considered in subsequent analysis.

Balancing the Positive and the Negative

Certain policy levers can also be used to alter the risk profile associated with entering a WiMAN market without changing the overall expected long-term financial outcomes. For example, city government might offer a positive subsidy, while demanding payments from the WiMAN provider(s) that are a fraction of profits rather than revenues, or that are due only after several years of operation.

4 Revenue Estimation

Revenue is an important factor when assessing financial sustainability. The best predictor of revenues from a future WiMAN is revenues from past WiMANs. At this early stage in WiMAN deployment, little revenue data is available. However, subscription levels are sometimes available. Because advertising rates are highly variable, we will make estimates assuming a subscription-based revenue model. We were able to find first-year subscription rates for eight WiMANs that derive all of their revenues from subscriptions, as opposed to advertising. (They are listed in Appendix A.)

We use regression to predict WiMAN subscription rates in the first year of operation as a function of demographic factors. We then apply that model in Pittsburgh and two other cities to estimate first-year subscription rates, and ultimately revenues.

There is significant uncertainty associated with this approach, because the number of data points is small, because the early adopters may not be entirely representative, and because next year's demand may differ from last year's demand. Nevertheless, we believe that predictions based on what data is available are useful and add new information to other estimates based largely on educated guesses.

It has been shown [14] that Internet usage is correlated with income, age, education, and race, so we predicted WiMAN subscribers per capita and WiMAN subscribers per household using 14 independent variables from the 2000 Census [15], each of which is related to income, age, education, or race.[7] We sought the best single-variable linear models, i.e. those with low p-value, high R^2, and high predicted R^2.

Based on our regression analysis (shown in Appendix B), median household income is the best single predictor of subscription. Median family income and percentage of population with a high school diploma are also useful predictors. Nearly every independent variable predicted subscribers per household more accurately than subscribers per capita. Thus, the most useful models predict subscribers per household as a function of median household income, median family income, and percentage of population with a high school diploma, respectively.

Table 1 shows the subscription rates at the end of the first year of operation predicted for Pittsburgh using the three best models. For comparison, subscription rates are also presented for Philadelphia and Minneapolis, because estimated subscription rates have been published for these two cities in their respective business plans [16, 17]. Our best prediction, which is based on median household income, is 36% lower than that stated in the Philadelphia business model, and 13% higher than that stated in the Minneapolis business model.

Table 1: Subscription per Household Predictions

Predictor	Pittsburgh	Philadelphia	Minneapolis
Median Household Income -0.108 + 0.00697 * Household Income (thousand $ / year)	**9.1 %**	**10.6 %**	**15.7 %**
Median Family Income - 0.158 + 0.00678 * Family Income (thousand $ / year)	**10.5 %**	**9.3 %**	**17.2 %**
Percent High School Grads - 0.615 + 0.972 * percent w/ H.S. Diploma	**17.5 %**	**7.7 %**	**21.1 %**
Published Estimates [16, 17]		**14.4 %**[8]	**13.7 %**[9]

[7] Some numbers may have changed significantly since the 2000 census, which is a possible source of error.
[8] The business plan [16] estimates 85,000 subscribers. Philadelphia had 590,071 households in the 2000 Census [15].
[9] The business plan estimates revenue of $7.5 million. Assuming a mean price of $28 per month, this corresponds to 22,321 subscribers. Minneapolis had 162,352 households in the 2000 Census [15].

Revenue is the product of the number of subscribers and average price per subscriber. Ideally, we would use the exact prices from the cities in our analysis. Determining average price is difficult, however, because each WiMAN offers a unique set of subscription services at different prices, differentiated by connection speed, extra features, and whether the subscriber is a business or individual. Consequently, we use a best guess average price of $28 per month, with a range from $24 to $32. This is consistent with available data from the 8 cities in our data set. We further assume that subscription levels grow linearly throughout the first year, starting at 0 subscribers, and at a constant percentage per day thereafter.

Revenue growth rate beyond year 1 is the final input needed. Unfortunately, few WiMAN systems have been operational long enough to yield long-term revenue growth data. The predictions published in the Philadelphia [16] and Minneapolis [17] reports vary drastically. Philadelphia estimates annual growth rates beginning at 40% and slowing to 5% over five years, with an overall annualized subscriber growth rate of 15.4% per year. Minneapolis optimistically estimates its revenue growth will begin at 140% between its first and second years, slowing to 26% after four years, with an overall annualized subscriber growth rate of over 60% per year.

We conclude that there is great uncertainty about the growth potential for WiMAN networks. For our analysis, we will assume that annual growth rate is between 5% and 15%, with a best estimate of 10%. This combined with our regression model based on median household income and a mean price of $28 per month leads to the five-year revenue projection shown in Figure 1.

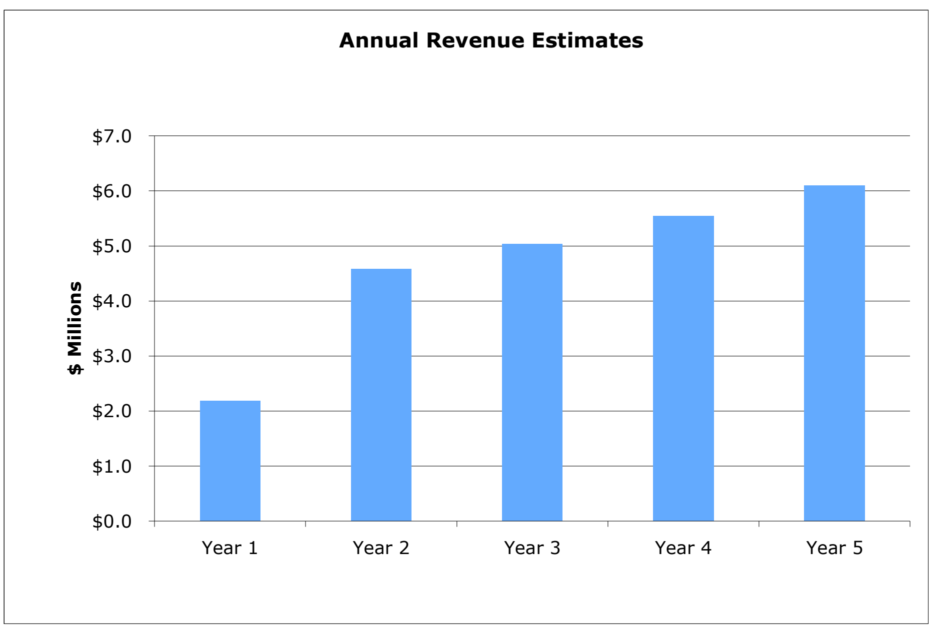


Figure 1: Annual Revenue Estimates for the WiMAN.

5 Cost Estimation

In order to determine whether a WiMAN model is financially sustainable, it is necessary to estimate costs. This section estimates initial build-out costs and ongoing costs over a five year period for a WIMAN serving Pittsburgh. We first approximate deployment costs through a survey of systems in other cities. We then estimate both deployment and ongoing costs that would be incurred in Pittsburgh with a sample architecture.

To get a first-order estimate of deployment costs, we surveyed similar systems, as shown in Appendix C. The mean cost per square mile was $111 thousand for all WiMANs, and a similar $110 thousand if we only consider WiMANs covering more than 20 square miles. If the costs were the same throughout Pittsburgh's 55.5 square miles, this would yield a deployment cost of $6.1 million.

To get a more complete picture that includes both deployment and operating costs, we designed a system for Pittsburgh based on one sample architecture. This may or may not be the optimal architecture for Pittsburgh, but it is a reasonable choice, and it builds upon lessons from a WiMAN that US Wireless currently operates in 2 square miles of Pittsburgh [18]. We chose a wifi-based system that is a hybrid of a mesh and hierarchical hub-and-spoke design. Numerous mesh networks will operate around the city, each of which includes one or more *relay* point, which aggregates traffic. Each relay is connected via a point-to-point wireless link to an *intermediate site*, and each intermediate site is connected via point-to-point wireless link to the WiMAN's central hub. This hub is connected directly to an Internet gateway.

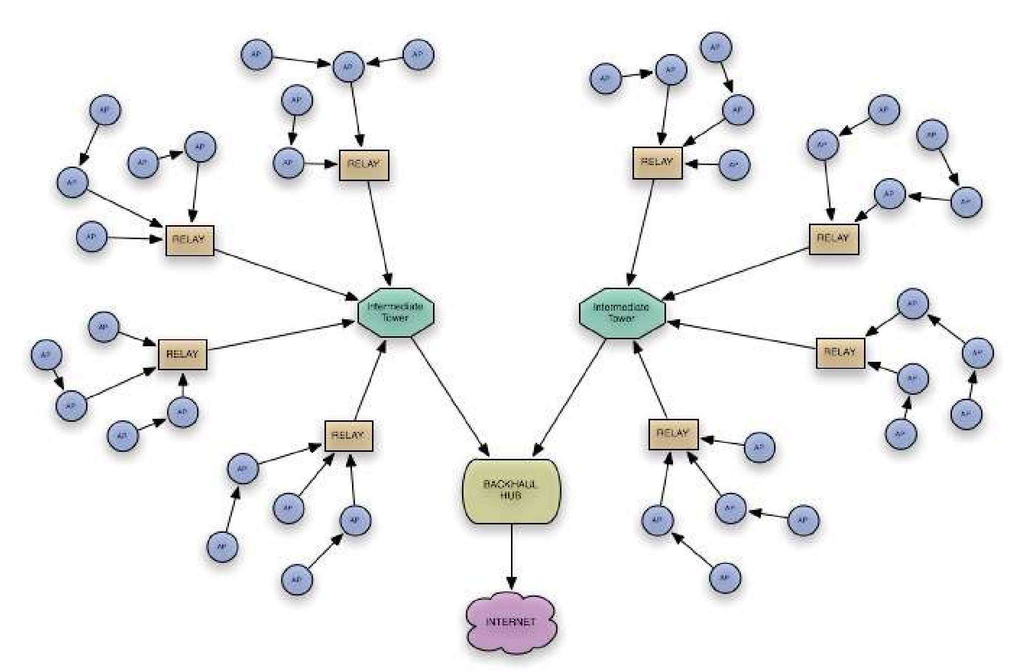


Figure 2: Architecture of the sample system

Appendix E shows the major costs with this architecture, based on assumptions summarized in Appendix D. The total deployment cost is estimated at $6.5 million. Roughly two thirds of this cost is associated with the access points. Consequently, the assumption about density of access points is particularly important. Appendix F shows the number of access points used or anticipated in a number of other WiMAN systems. This number varies greatly, in part because of terrain, types of buildings, and coverage objectives. For example, there were 25 access points per square mile in a WiMAN covering 2 square miles of Downtown Pittsburgh [18]. A much lower access point density will suffice in the rest of Pittsburgh, because Downtown has a particularly high concentration of tall buildings. Based on experience in Downtown Pittsburgh and in other cities, we estimate roughly 19 access points per square mile for a system covering Pittsburgh.

Major operating costs include maintenance staff, leasing fees, advertising and connectivity with the Internet. Appendix G lists annual operating costs other than sales and marketing, as well as some assumptions behind them. Experience with other ISPs shows that advertising and other marketing costs are often higher initially to attract new customers to the network. Based on such experience [19], we assume costs of $1 million in Year 1, $800 thousand in Year 2, and $500 thousand from Years 3 through 5. Since these costs vary from market to market, there is probably greater uncertainty for this portion of cost. However, all these costs combined are small compared to build-out costs. Figure 3 shows total costs, including build-out and operations.

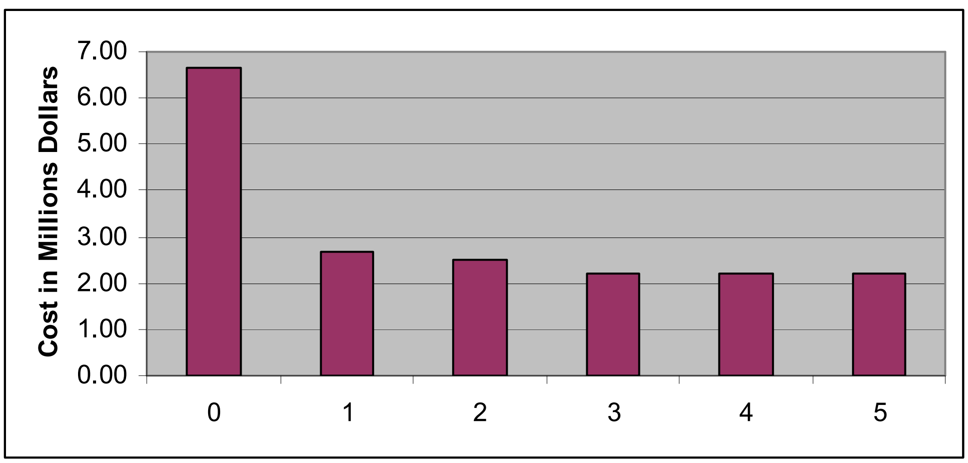


Figure 3: Estimated Yearly Cost of the network, including installation and operating costs

The above figure shows that the costs to build the WiMAN were much greater than annual costs, and these costs must be incurred before revenues can begin. This implies that it will be challenging to find the resources to launch a new WiMAN, and much easier to make the WiMAN self supporting in subsequent years. We also note that the largest part of deployment cost is proportional to the number of access points. This implies that the extent of coverage is an important determinant; because wifi has a short range, a 5% reduction in coverage can often significantly reduce the number of wifi access points needed.

6 Financial Sustainability of each WiMAN Model

Based on the cost and revenue estimates above, we assess the likelihood of financial sustainability for each of the four WiMAN models over five years of operation plus one year of build out using discounted cash flow analysis. For the purpose of this analysis, a model is considered sustainable when the projected revenues exceed projected costs and provide an appropriate return on investment, which might be used as the discount rate. This section includes a discussion of the general methodology for assessing the four business models, one subsection for each of the four business models, and a final comparison of models.

All values are assessed in today's dollars. The sustainability of each cash flow is assessed by calculating its net present value and modified internal rate of return. This analysis relies on a host of variables, each of which introduces a degree of uncertainty. In evaluating each model, we use a base case in which all variables are set to values that seem most reasonable, and a sensitivity analysis that evaluates the effect of misestimates in the input variables on the final outcome. The key variables and assumptions in these analyses include:

Discount rate —As a base case assumption, we assume a discount rate of 8.25%, which is prime rate at the time of this analysis. Any entity deciding whether or not to undertake the WiMAN project will have to deduce its own cost of capital.

Project timeframe — We assume WiMAN providers will assess sustainability over a six-year time frame (including build-out Year 0), during which today's wifi technology remains widely used.

Tax: All of the earnings we consider are on a pre-tax basis. In much of our analysis, we only consider time frame to breakeven, so tax would not be a major issue. However, once the project has broken even, this could be a significant cost.

Revenues: As a baseline, we assume year 1 subscription rate, subscription growth rate (10%/year), and average subscription price ($28/month) are set at levels presented in Section 5.

6.1 Citywide Monopoly

As described in Section 2, the first model for a WiMAN involves a single Internet service provider (ISP) building, maintaining, operating, and owning a citywide network in Pittsburgh. This ISP will incur all of the costs for the project, as well as receive all of the revenues.

The five-year cost and revenue estimates discussed above yield a net present value (NPV) of $1.85 million, and the cash flow shown in Figure 4. The monopolist would break even in Year 5, where Year 0 is the build-out year. This implies that commercial companies would seriously consider deploying a citywide WiMAN in Pittsburgh under the right circumstances, e.g. if profit is commensurate with risk..

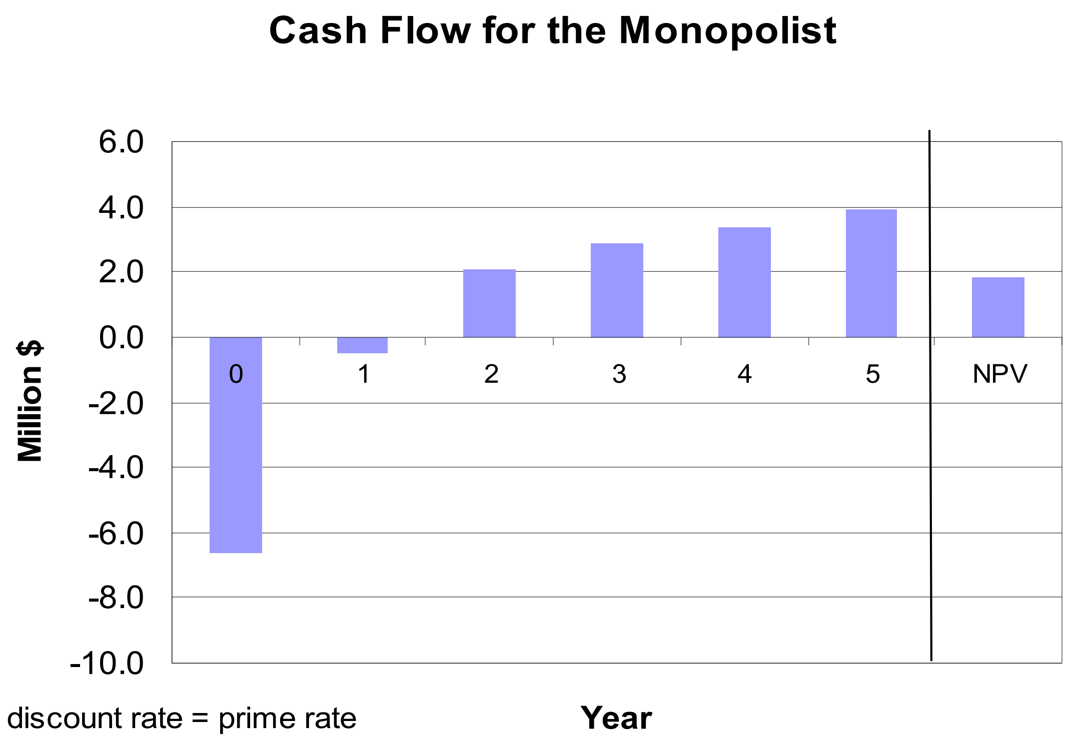


Figure 4: Cash flow and NPV for the monopolist from Year 0 to Year 5.

Figure 5 shows how NPV changes if one of these values varies from baseline assumptions: total installation cost, discount rate, mean monthly subscription price, number of subscribers at the end of Year 1, and annual subscriber growth rate. While a citywide monopoly is sustainable under baseline assumptions, this sensitivity analysis shows that an unsustainable outcome is easily within the margin of error. Although there is some uncertainty associated with deployment cost, any inaccuracies are probably too small to yield a negative NPV. In contrast, uncertainties related to future revenues are substantial, and inaccuracies could easily yield a negative NPV.

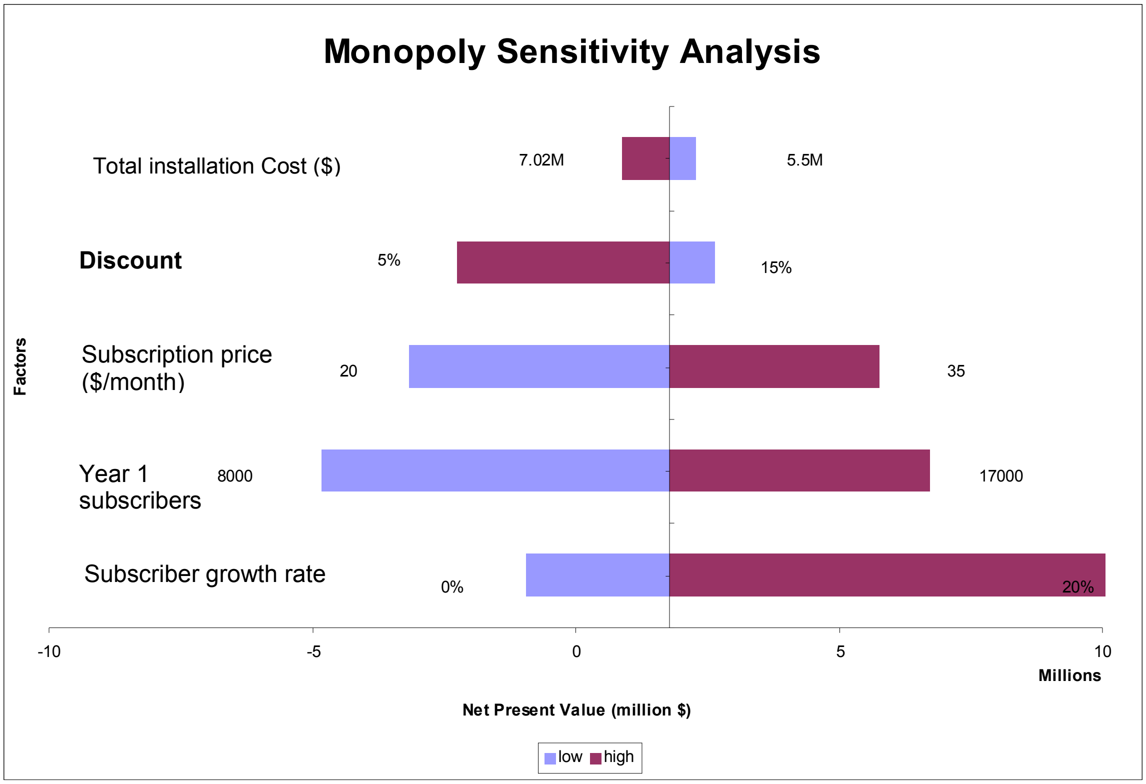


Figure 5: The vertical line represents a monopolist's NPV under baseline assumptions. Each horizontal line shows how NPV changes with one variable, while all other variables remain at baseline.

6.3 Facility-based competition

The facilities-based competition model assumes there are multiple providers that each builds a separate citywide WiMAN. We assume costs for each WiMAN would be the same as for a monopolist. In this scenario, competitors split the same customer base. For simplicity, we assume that the providers split the revenue equally, and that total revenues are the same in this model as in the monopoly model. In reality, the increase in competition may decrease total revenues, which would make our estimate optimistic.

Figure 6 shows the NPV and cash flow for Years 0 to 5 with 1, 2, and 3 competing WiMAN providers under baseline assumptions. With just two competitors, our model predicts a NPV of -$5.5 million per provider. Clearly, citywide competition is not sustainable without some kind of intervention.

As discussed in Section 3, there are a number of ways to improve the sustainability of a WiMAN. Some interventions have the effect of improving year 0 cash flow, such as providing an initial one-time subsidy, or covering some of the provider's initial costs. Other interventions have the effect of improving annual cash flow beginning in year 1, such as becoming a large anchor customer, or giving the WiMAN access to light poles at a price that is below market rates. For two providers to achieve an NPV of

0 after Year 5 under baseline assumptions, a Year 0 intervention must be worth $5.5 million, and an annual intervention must be worth $1.4 million per year. In contrast, a monopoly provider benefiting from the same intervention would reach an NPV > 0 during Year 3, and would be highly profitable after that.

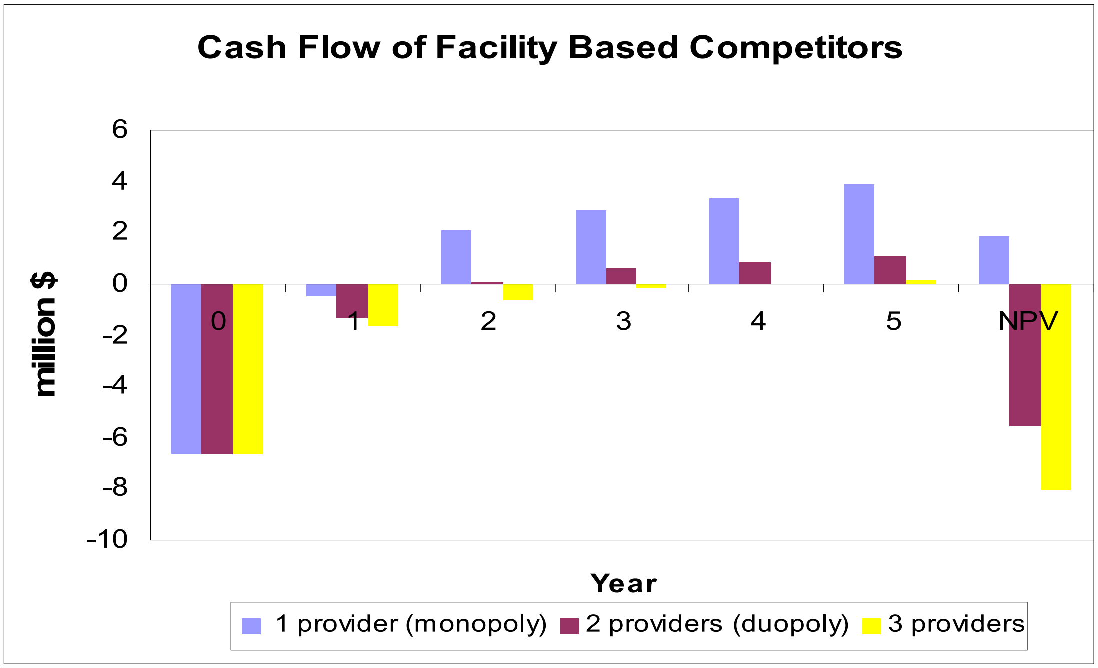


Figure 6: Cash flow and NPV for *each* service provider under facility-based competition with one, two, and three providers.

6.4 Wholesale-retail model

The next model we consider consists of one wholesaler which is responsible for the costs of building and operating the citywide wireless network, and multiple retail Internet service providers, each of which are responsible for their own costs for customer service, billing, ISP web sites, and connectivity with the Internet backbone. Since there is some duplication of effort among retailers, total costs increase as the number of retailers increases. For example, each retailer is responsible for its own web site, billing, customer support, and customer acquisition. We assume that total revenue is the same for this model as in the two previous models, and that revenues are split equally among retail ISPs. In general, either the wholesaler or the retailers could provide connectivity to the Internet. Here, we consider the former option. We assume that half of the marketing costs incurred by a monopoly are for the promotion of WiMAN service in general, and can be split equally among the retailer. The other half are for promotion of a specific retailer, and must be duplicated by each retailer.

Under baseline assumptions, the wholesaler would break even with a 5% return on investment at the end of Year 5 if the combined payments from competing retailers equal $2.68 million per year. A 5% rate of return is presumably too low for a commercial wholesaler, but may be acceptable to a non-profit organization.

Figure 7 shows costs incurred by the wholesaler and the total costs incurred by all retailers, in scenarios with 1, 2, and 3 retailers, respectively. The figure shows costs for retailers excluding the payments to the wholesaler, and it shows costs for retailers including total payments to the retailer of $3.3 million per year. Clearly, the initial costs for a wholesaler are large, but annual costs are much lower after build-out. Thus, one of the challenges for this model is funding the initial build-out of the wholesaler's network, but the model becomes more viable after that.

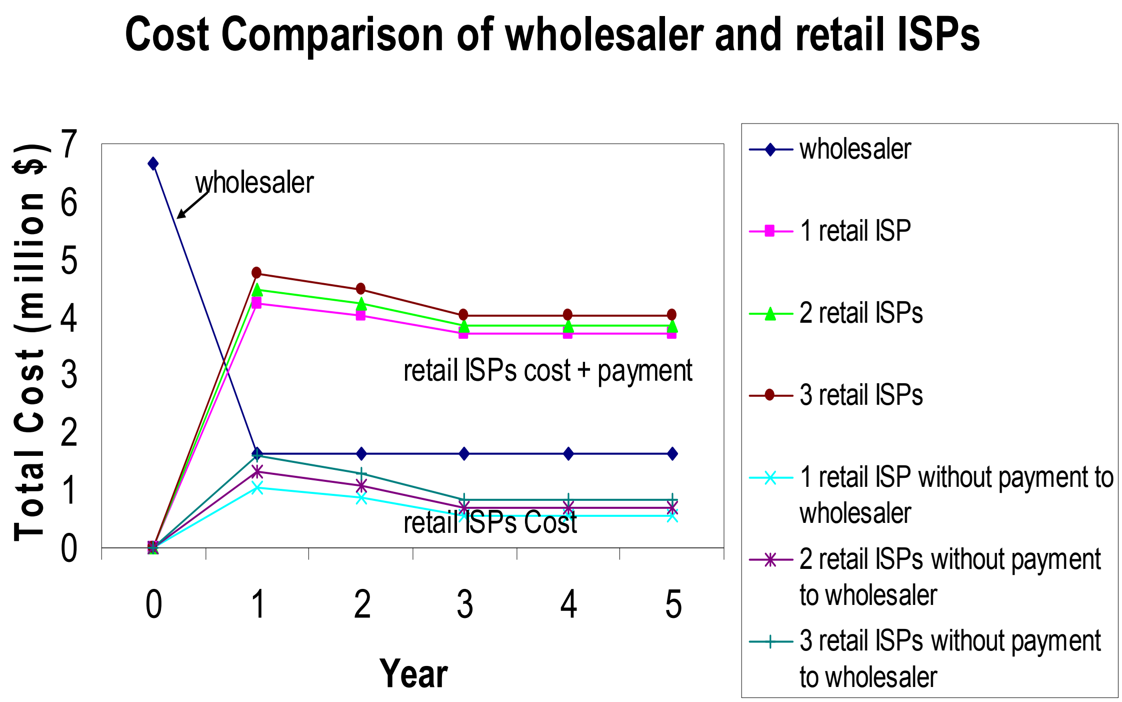


Figure 7: Cost comparisons of wholesaler and retail ISPs. Payment refers to the payment from retailers to the wholesalers.

Figure 7 also shows that increasing the number of retailers has a small impact on total costs, which should alleviate a serious concern about this model. This implies that sustainability under this model should be similar to that of the monopoly model. Moreover, even if the wholesaler accepts a return on investment of just 5%, the majority of a retailer's expenses consist of payments to the wholesaler. Thus, we evaluate the sustainability of retailers in Figure 8 under the more pessimistic assumption that the wholesaler requires an 8.25% return. Still three retailers can show an NPV > 0 at the end of Year 5 under baseline assumptions. This wholesale-retail split may be attractive for cities like Pittsburgh. It offers some degree of competition, and citywide coverage.

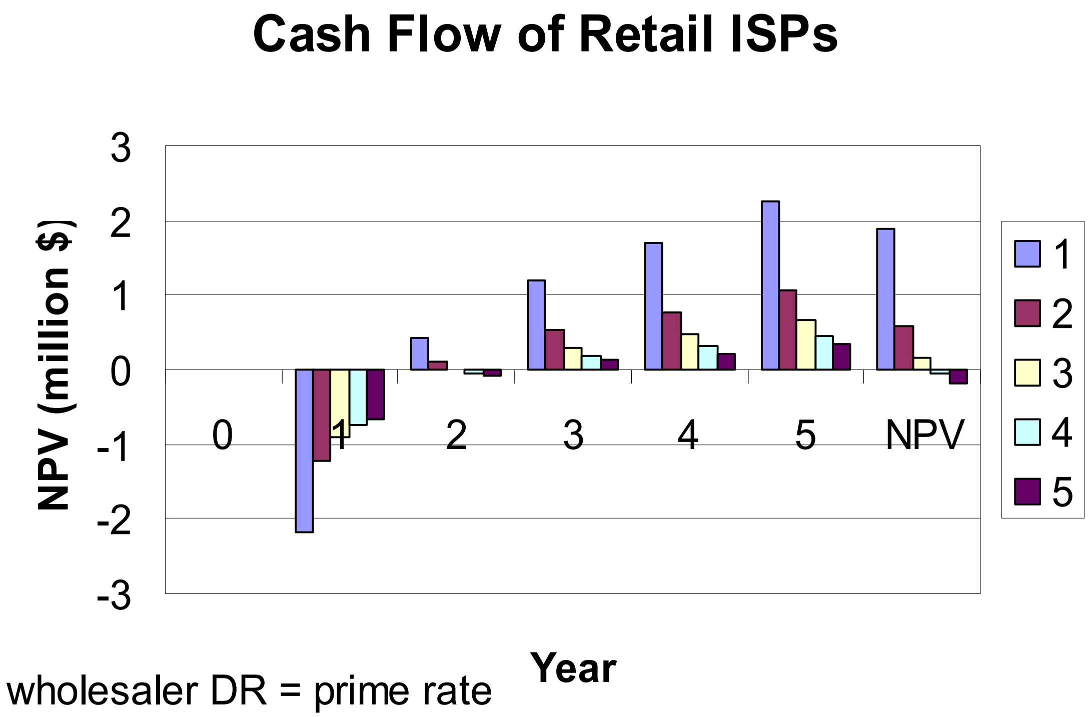
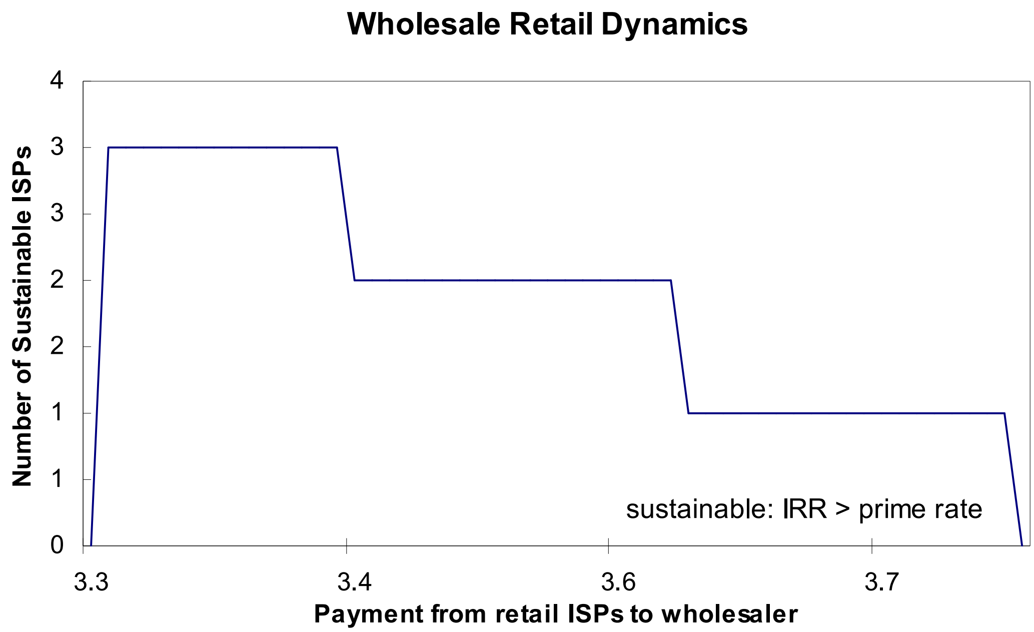


Figure 8: Cash flow and NPV for each retail ISP, where the wholesaler's discount rate is 8.25%

However, if the wholesaler is a commercial company, it may not be satisfied with a 5% or an 8.25% rate of return. Figure 9a shows that the number of sustainable retailers decreases as the payment from retailers to wholesaler increases. Figure 9b shows that a profit-seeking wholesaler has strong incentive to increase these payments until reaching a point where only one retailer remains. Thus, retail competition is unlikely to survive unless the City can somehow motivate the wholesaler to keep its rates sufficiently low. This may be easier if the wholesaler is a non-profit organization.



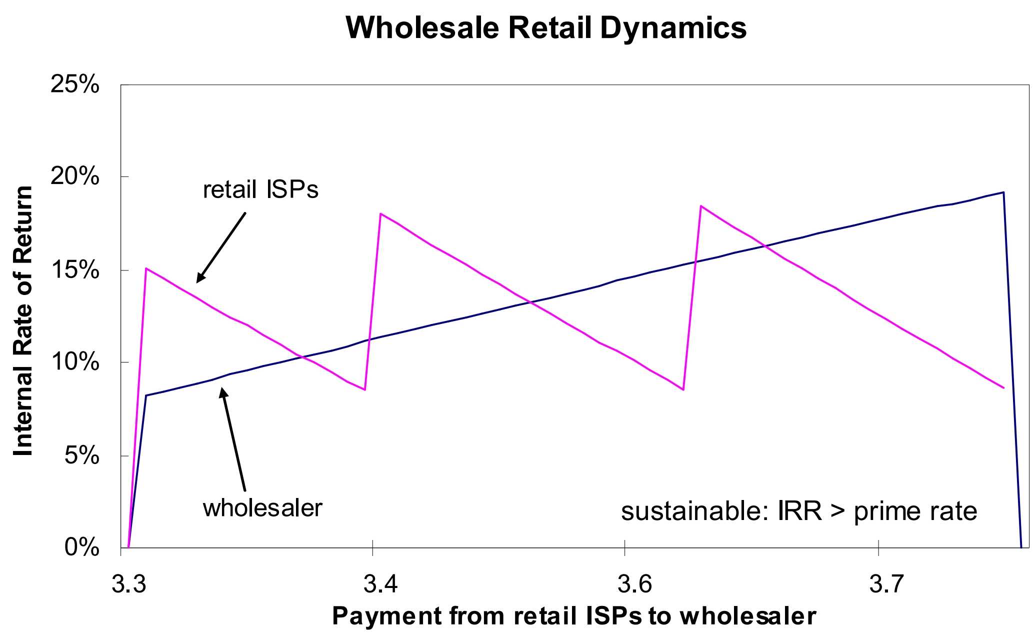


Figure 9: (a) number of sustainable retailers vs. payments from retailers to wholesaler in million dollars per year. (b) internal rate of return for wholesaler and retailers vs. payments from retailers to wholesaler, assuming number of retailers is the maximum sustainable.

6.5 Neighborhood-by-neighborhood competition

In this section, we examine the model in which ISPs are free to choose the neighborhoods where they provide service. To assess sustainability, we assume that 1) the best model in Section 2 designed to predict city subscriber rate can also predict subscriber rate in each of Pittsburgh's 90 official neighborhoods, and 2) the cost per square mile is constant throughout the city and equal to that of the citywide WiMAN. These assumptions are major simplifications and do not reflect the effect of economies of scale, among other factors, so this estimate is strictly a first-order approximation.

Figure 10 shows the cumulative distribution function (CDF) of neighborhood NPV weighted by population and area, respectively, under baseline assumptions. If we assume that neighborhoods with estimated NPV < 0 at the end of Year 5 would not be served, then more than 50% of Pittsburgh's area will be unserved, and 40% of the population. This would constitute a substantial digital divide. The neighborhoods that generate enough revenues to sustain two or more competitors cover roughly 30% of Pittsburgh's area, and are home to roughly 40% of Pittsburgh's population.

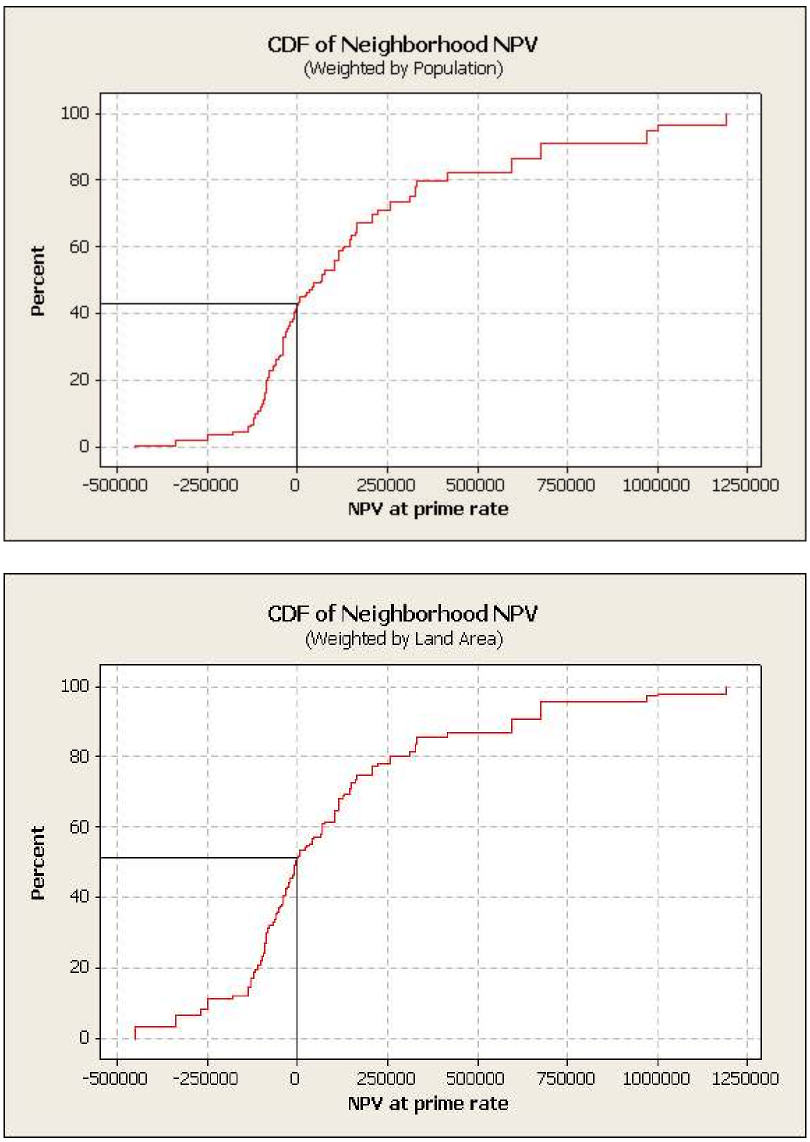


Figure 10: CDF of neighborhood NPV weighted by population (top) and area (bottom).

Given our underlying assumptions, there is significant uncertainty in these results. Further research is required. Nevertheless, these results are consistent with the premise that a commercial provider would choose to serve only a small subset of the city, unless city government or another player can exert some form of leverage or offer some incentive to serve the entire city.

6.6 Model Comparisons

Figure 11 compares the NPV over Years 0 through 5 for each of the citywide WiMAN models discussed above. The wholesale-retail split has a somewhat lower NPV than a monopoly, in part because we are combining the NPV of the wholesaler (which was previously set to 0 at an 8.25% discount rate) and the NPV of the retailers. Nevertheless, the NPV of the wholesale-retail split compares reasonably well considering that the added possibility of competition. In contrast, facilities-based competition citywide is clearly problematic.

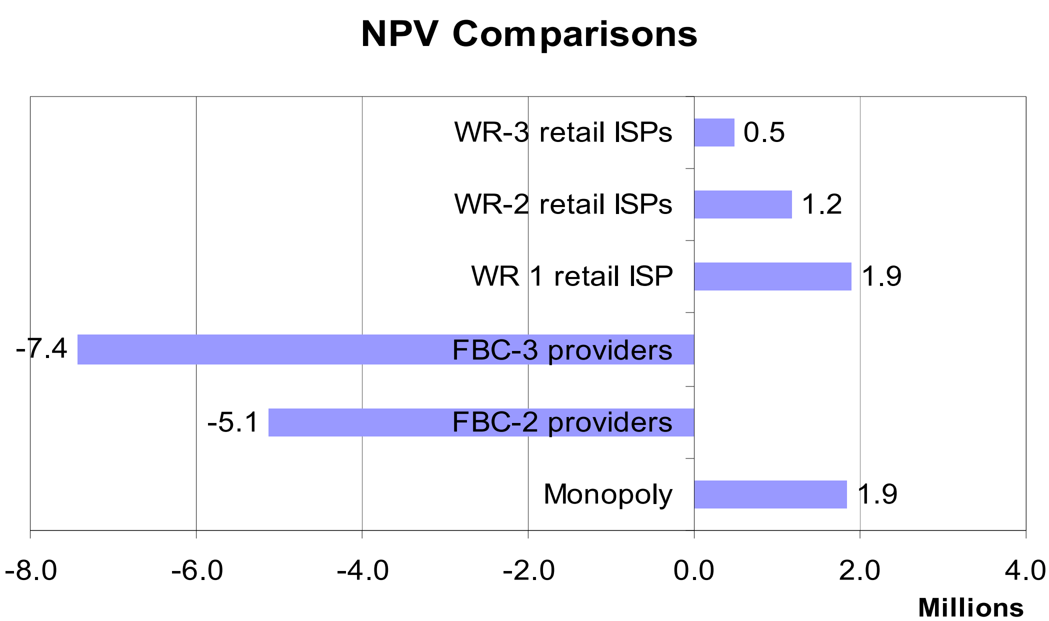


Figure 11: Estimated NPV for a monopoly; facility based competition (FBC) with two providers and three providers; and wholesale-retail split (WR) with one, two and three retail ISPs.

7 Conclusions

We found that the cost to initially deploy a citywide WiMAN is considerable. Our estimate for Pittsburgh based on a sample architecture was $6.5 million, which is consistent with the cost per square mile in other cities. This initial cost dominates subsequent yearly costs of $2.2 to $2.7 million. We also developed a regression model to predict subscription rates. Our most effective revenue estimates were based on a city's median household income. Using this, we projected significant revenues in Pittsburgh, but given the paucity of directly relevant data, there is great uncertainty in these estimates. This uncertainty will decline as more cities deploy these systems.

Based on our analysis of NPV after five years of operation, we found that both a citywide vertically integrated monopoly and a citywide wholesaler with competing retailers could be financially sustainable in the City of Pittsburgh. However, the high uncertainty related to revenues means that an unsustainable outcome is within our margin of error. This, combined with the high initial costs, imposes a difficult challenge on would-be WiMAN providers in any city, particularly for commercial enterprises. Cities that want to increase the chances of achieving sustainability without running their own WiMAN might adopt interventions that reduce risk. Some such interventions would cost the City little if the WiMAN proves to be financially successful, but may cost a great deal if the WiMAN fails. For example, the City might provide funding only in the difficult start-up period or underwrite an initial advertising campaign in return for a share of profits after the WiMAN becomes successful or in return for free services for government agencies or low-income households.

The potential for facilities-based competition among citywide providers was more bleak. Even with the uncertainties, it is unlikely that this model is sustainable in Pittsburgh or comparable cities. Indeed, this wifi-based network appears to have many qualities of a natural monopoly (in a WiMAN market, not a broadband market). This is ironic, given the conventional wisdom that the economics of wireless make it more conducive to facilities-based competition than cable or telephone systems. The reason for this anomaly is that wifi technology was designed to serve small areas, so blanketing an entire city with wifi requires a large capital investment. Very different results are possible with another wireless technology that operates at higher power and has greater range. The economics would also be quite different if many wifi access points were purchased by consumers instead of an ISP, which is technically possible, but raises serious security issues that we are still trying to address [20].

Facilities-based competition may be unsustainable, but retail competition atop a single citywide wholesaler was found to be almost as financially sustainable as a vertically-integrated monopoly. This makes the wholesale-retail split a potentially attractive model for cities like Pittsburgh. A serious concern is that retail competition is highly dependent on rates charged by the wholesaler. We demonstrated quantitatively how a wholesaler maximizes its return by setting this payment at a point where only one retailer survives. Many cities have adopted this model with a commercial wholesaler such as EarthLink. Thus far, retail competition seems viable. However, it is no surprise that a wholesaler would encourage retailers to compete in the early days of a WiMAN, when marketing costs are high and revenues are low. These commercial wholesalers may raise their fees considerably when more people have subscribed. This danger is probably smaller if the wholesaler is a non-profit organization (as in Boston) or a government agency, but some danger remains. Note also that prohibiting the wholesaler from offering its own retail service, as some have proposed, does little to address the risk.

We have also considered a model where vertically-integrated providers operate only in the neighborhoods where profits are expected. Although the uncertainty in this analysis is considerable, we found that much of Pittsburgh would remain unserved. This is consistent with observation; various groups are now discussing the creation of neighborhood WiMANs in Pittsburgh's more affluent neighborhoods.[10] This implies a risk that wifi will exacerbate the digital divide rather than reduce it.

The above concerns raise a broader and largely-neglected issue: a city's *leverage*. Listening to the political debate might make one think that government leaders are free to decide what a city's WiMAN will look like, even if it is commercially-run. Will a WiMAN serve low-income neighborhoods? Will it allow competing retailers to operate over its infrastructure, and if so, will it charge those retailers reasonable prices? Will the WiMAN offer free or discounted services to the general public or to certain groups? Will it facilitate convenient access over a larger area by establishing roaming agreements with other WiMAN operators? Reasonable minds may differ on the importance of some of these questions, but we can agree that city government can influence the answers if and only if it has a significant source of leverage.

Leverage can take many forms. One important example is the ability to give a provider access to light poles, and other sites for access points. Our analysis shows that the leasing of this space is a significant part of operating costs. Moreover, the flexibility to place access points at optimal locations decreases deployment costs. However, in many cities (including Pittsburgh), city government directly controls access to only a small fraction of light poles.[11] Alternatively, a city can gain leverage by becoming the WiMAN's anchor tenant, perhaps in combination with other large institutions. Note that it is not enough for the City to eventually make heavy use of WiMAN services as some city governments might prefer. To gain leverage as an anchor customer, the City must enter into a long-term commitment to be a heavy user, ideally well before the WiMAN provider has invested much money in the build-out. In some cities, civic-minded companies and non-profit organizations are seeking ways to facilitate the creation of a citywide WiMAN. They can also exert leverage if the choose, by providing funding, granting access to useful resources like light poles or fiberoptic backbones, becoming anchor customers, or even becoming a non-profit wholesaler. If city government and other important players cannot employ these or other sources of leverage, and will not pay the considerable cost of building a WiMAN, the city should content itself with whatever WiMAN model the market produces. In the long term, this is unlikely to be a wholesale-retail model, or to be ubiquitous.

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[10] For example, merchants in the high-income Pittsburgh neighborhood of Shadyside have established a wifi system that covers many shops, bars, restaurants, and homes.
[11] In Pittsburgh, many light poles are controlled by the power company, Duquesne Light.

8 Project History and Acknowledgements

After wifi service became available in two square miles of downtown Pittsburgh, many city residents and leaders wondered about the possibility of citywide services. From August to December of 2006, Professor Jon Peha and 21 CMU students conducted a study to provide useful information and analysis to the Pittsburgh City Council, and other city leaders. A subset of that group continued research into Spring of 2007, and wrote this paper. The authors wish to thank

- Councilman Bill Peduto, who has long been active in this area, who encouraged CMU to conduct a study, who served as the primary representative of our client - the Pittsburgh City Council, and who convened a formal City Council Hearing to discuss our results.
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10 Appendices

Appendix A: First-year individual and business subscribers in cities that derive revenues exclusively from subscriptions for which data were available

City Name	First-year subscriptions	Subscriptions per captia	Subscriptions per household
Buffalo, MN [21]	1150	11.4%	31.1%
Chaska, MN [5]	1551	8.9%	25.4%
Galt, CA[22]	1100	5.6%	18.4%
Linden, TX [23]	40	1.8%	4.3%
Moorhead, MN [24]	2200	6.8%	18.9%
Nevada, MO [25]	150	1.7%	4.3%
Scottsburg, IN [23]	400	6.6%	15.8%
Vivian, LA[26]	55	1.4%	3.5%

Appendix B: Regression Results

	Subscriptions / Household			Subscriptions / Capita		
Independent Variable(s)	**P-Value**	**R-Sq**	**R-Sq (Pred)**	**P-Value**	**R-Sq**	**R-Sq (Pred)**
Median Household Income*	**0.003**	**80.3%**	**52.9%**	**0.008**	**71.1%**	**39.8%**
Median Family Income*	**0.004**	**77.7%**	**44.7%**	**0.009**	**70.9%**	**33.6%**
Income Per Capita*	0.009	71.0%	0.0%	0.011	68.9%	0.00%
% of population over 25 years old with High School Diploma or equivalent	**0.013**	**67.4%**	**44.3%**	**0.017**	**64.3%**	**37.7%**
% **of population over 25 years old** with College Degree	0.059	47.3%	0.0%	0.068	45.2%	13.8%
% Household Income > $150k	0.074	43.9%	16.6%	0.07	44.7%	0.0%
% Black (self-identified)	0.074	43.8%	3.0%	0.08	42.5%	4.5%
Median Age	8.3%	41.8%	11.2%	0.105	37.7%	1.4%
% White (self-identified)	0.173	28.4%	0.0%	0.146	31.7%	0.0%
% Between 15 and 35 years old	0.196	26.1%	0.0%	0.184	27.3%	0.0%
% Family Income > $150k	0.198	25.8%	0.0%	0.219	23.9%	0.0%
Mean people per household	0.227	23.2%	0.0%	0.371	17.6%	0.0%
% of population enrolled in college	0.285	18.6%	0.0%	0.699	2.7%	0.0%
% Asian (self-identified)	0.936	0.0%	0.0%	0.980	0.0%	0.0%

Appendix C: WiMAN Deployment Costs[12]

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City, State	Network Size (sq. miles)	Cost ($ Millions)	Cost per Square Mile ($ Millions)
Corpus Christi, TX [27]	147	$7	$0.048
Philadelphia, PA [28]	135	$15	$0.111
Portland, OR [10]	134	$10	$0.075
Boston, MA [7]	86	$18	$0.209
Anaheim, CA [29]	43	$6	$0.140
Tempe, AZ [30]	40	$3	$0.075
Chaska, MN [31]	16	$0.535	$0.033
St. Cloud, FL [32, 33]	15	$3	$0.200
Ashland, OR [34]	7	$1	$0.143
Athens, GA [35]	1	$0.075	$0.075
Mean for all cities			**$0.111**
Mean for WiMANs ≥ 20 square miles			**$0.110**

[12] In some cities, these are deployment costs, and in some, they are actual costs.

Appendix D: Cost Assumptions

Assumptions
19 access points per square mile, as discussed in Section 5
Access points cost $3,500 each [36, 37]
Each access point needs a power supply as well as a mounting kit for attaching to building/light pole [38]
Power supplies cost $290 each, including cable
1 relay per 5 access points [38]
Cost of a relays is $4150 [38]
Each relay and each access point needs a mounting kit which cost $230 each
Each intermediate site can service a 10 mile radius [38]
Four intermediate sites will cover Pittsburgh
There are an average of 3.5 small sites for every intermediate site [38]
Each small site costs $25,000 [38]
It takes 2.5 hours to install an access point, and 3 hours to install a relay [38]
There will be one service van for each intermediate site [38]
Vans cost $25,000 each
It takes 200 hours to design the network [38]
You use the same software to design and monitor the network with costs $45,000 [39]
The entire network can be built in one year
Website design is a one time cost of $15,000 [38]

Appendix E: Expected cost for initial build-out

Cost Item	Expected Numbers	Expected Cost	Total Expected
-APs	1055	$3,500	$ 3,693,000
-AP Power Supply and Cable	1055	$290	$ 306,000
- AP mounting kit	1055	$230	$ 243,000
-Relays	211	$4,150	$ 876,000
-Relay mounting kit	211	$230	$ 49,000
-Intermediate sites	4	$50,000	$ 200,000
-Small-Sites	14	$25,000	$ 350,000
-Backhaul hub	1	$100,000	$ 100,000
Installation Labor (APs and Relays)	3300 hours	$125/hour	$ 412,000
Vans	4	$25,000	$ 100,000
Design Labor Costs	200 hours	$75/hour	$ 15,000
Design Software Costs	1	$45,000	$ 45,000
Servers	8	$1,200	$ 10,000
Web Design		$15,000	$ 15,000
Totals			$ 6,414,000

Appendix F: Access Points Per Square Mile in Various Cities

City	APs per sq. mi.
Corpus Christi, TX [40]	16
Philadelphia, PA[41]	12
Portland, OR [42]	22
Boston, MA [43]	45
Anaheim, CA [44]	30
Chaska, MN [45]	16
St. Cloud, FL [46]	20
Mountain View, CA [47]	33
San Francisco, CA [47]	30
Pittsburgh, PA Downtown [18]	25
Average	24.9

Appendix G: Annual costs, excluding marketing

Type of Expenditure	Expected Cost Assumptions		Estimated Annual Cost
Server Hosting	$1.10 per GB data transferred	600 GB of data per month	$8,000
Power	$0.12 per kW hour. Access points consume 18 Watts and relays consume 8 watts	1055 access points and 211 relays	$22,000
Registration/ Login Page Maintenance	$35 per hour for labor	50 hours per month	$21,000
Leasing Space for Small sites	$150 per month per site	14 sites	$25,000
Leasing Space for Intermediate sites	$700 per month per site	4 sites	$34,000
Customer Support	a customer calls once per year at $2.50 per call [48]	13,000 subscribers	$32,000
Bandwidth[13]	$40,000 per month	At least 150Mbps needed	$480,000
Maintenance Staff	Cost per technician: $61,250 for base salary and overhead expenses [38]	1 Technician for every 100 access points	$674,000
Leasing Space on Light Poles	$30 per month per light pole	1055 light poles needed	$380,000
Equipment replacements	Average of 4 access points or relays will fail per year	$3500 per failure	$14,000
Total			$1,690,000

[13] The need of a Pittsburgh WIMAN bandwidth is estimated to be a 155Mb/s OC-3 line, as a 1.5 Mb/s T-1 can support 100-200 users [49].