LOCATION OPTIMIZATION TO DETERMINE TELECENTER NETWORK IN RURAL TURKEY

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ABSTRACT

In different parts of the world, telecenters have been in use to make people get benefit from information and communication technologies (ICT). In those centers disadvantaged people can access internet and use electronic services offered in a broad range. And rural inhabitants are among these disadvantaged people. Telecenters are required in rural areas not only to make people utilize ICT but also to contribute rural development.

Electronic services bring about many opportunities for citizens in both daily and professional life. With the use of them, it is possible to raise living standards and increase productivity. ICT has a special importance for rural areas as ICT-supported implementations help people in rural areas reach information, services and markets that are hardly accessible in traditional ways. Therefore, rural telecenters are established and electronic services meeting rural requirements are served through them.

In general the biggest challenge for telecenters is their sustainability. In rural areas this problem gets even bigger as demand for such services are relatively lower because of the lack of awareness and motivation. Thus they need to be carefully designed to ensure their sustainability and efficient use. For sure, their sustainability mostly rests on the electronic services offered to rural inhabitants through these centers. However, to ensure efficient use of them and also to serve everyone in the area, their location, number and capacity gain utmost importance, too.

Regarding the low demand and the difficulty to sustain telecenters in rural areas, the best approach is to establish those centers in only select hub settlements to be reached easily from the villages in close vicinity. In this study, optimization methods were used to determine the location of those rural telecenters. Three location optimization problems as set covering, p-center and p-median were defined and then

solved. In the set covering problem the number of the centers was minimized given a maximum travel distance from origin to destination, in the p-center problem the maximum distance between the destination and the village served from there was minimized given the number of telecenters required and in the p-median problem total travel distance in the area was minimized again given the number of telecenters. While each of the three models aims to serve all the villages in the area, their results differ reflecting the priority of that approach.

BIOGRAPHICAL SKETCH

Ozlem Asik attained her Bachelor's Degree in City and Regional Planning from Middle East Technical University, Ankara, Turkey in 1997. She also obtained a Master's Degree in Geodetic and Geographic Information Technologies from the same university in 2001.

She has worked in both public and private sectors in Turkey since 1997 and is also currently an employee of Ministry of Development. In 2011 she started to study at Cornell as a government-sponsored fellow. She gained her Master's Degree in Regional Science at Cornell University in 2013.

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CHAPTER ONE:

Introduction

During the last two decades the world has witnessed a huge transformation. Within that period the knowledge has been used in daily life and business world more than ever giving rise to new life styles, new occupations and innovative ideas while the related technologies named information and communication technologies (ICT) has improved tremendously coping with this demand. Still, world has been becoming more digital every day and bringing new opportunities.

In production processes and working environment ICT increases productivity and this leads to growth. Integration of ICT into professional life is good but not enough because extensive and efficient use of those technologies throughout the country, which leads economic returns to arise more and faster, is required. However, one of the challenging subjects in creating this is the differing usage level of people, known as digital divide. While these technologies are not accessible for everyone and thus some groups of people are already disadvantaged, those who can't utilize them are further threatened by being much behind of others because of the inaccessible opportunities and services offered on the internet. To solve this problem, several policies have been suggested and adopted, and one of these is "telecenters" where the disadvantaged people can use such technologies.

In Turkey also, telecenters have been accepted as an efficient way to reduce digital divide. This initiative started in 2006 and a number of telecenters have been established mostly in bigger settlements since then. They were quite similar to each other, however, regarding its great mission and the variations in society, it was necessary to design several types of them differing in size and the electronic services offered regarding the background and demands of local users. From this point of view, to reduce digital divide between urban and rural, one type should be rural telecenters where rural inhabitants can use electronic services meeting their needs.

As well as playing an important role for the digital inclusion of rural inhabitants, telecenters also provide rural people with new opportunities in many fields which will accelerate rural development. The opportunities supported by ICT can be various. The foremost of them is the quality service provision in education and health sectors, which are the basic services supported mostly by the government. ICT can compensate the disadvantages in the quality and accessibility of these services and be a good complimentary and contributory of the service providers. Human resources, which is lower educated or unqualified in rural areas, can be developed through e-learning. ICT can increase accessibility to technical support and consultancy services that plays an important role for the productivity increase in production processes to have a competitive and sustainable agricultural sector, which is the dominant economic activity in rural areas. As well as the improvement in agricultural sector, the development of non-agricultural economic activities and the improvement in accessing financial resources and markets can also be supported by ICT, all of which give rise to better rural income. Another issue ICT can facilitate is the relation between the government and the rural inhabitants and enterprises. ICT can simplify bureaucratic procedures and remove the necessity to visit distant public institutions by means of e-government services. This and the encouraged participation of citizens in public administration through ICT both lead to empowerment of rural citizens. Therefore, it is clear that ICT is a great opportunity to accelerate integrated rural development, to achieve socio-economic improvement for rural citizens and to reduce digital divide.

The main issue and the biggest challenge for telecenters is to sustain their continuous operation. Demand-oriented, up-to-date electronic services having dynamic structure are the key to attract people to those places and make the centers operate well. The desired long operational hours of telecenters requires flexible and creative management models that are not currently available. Location of telecenters is also important for how often and how easily people can visit them. Therefore, regarding the low demand for ICT in rural areas and the challenges for telecenters in general mentioned above, establishing telecenters in select hub settlements is a better solution rather than getting all the villages have one. Those telecenters then will serve both the settlements where they are located and the villages around.

This thesis aims to optimize the location of telecenters in a limited number of rural settlements provided that all of the villages will be served by those telecenters. Several operations research methods have been used in location optimization for years and here three optimization problems among them were selected and solved. The first problem, which is the set covering model, aims to minimize the number of telecenters while taking into consideration an exogenously determined travel distance. The second problem, which is the p-center model, aims to minimize the maximum distance between origin and destination pairs given the number of telecenters determined exogenously. And the third problem, which is the p-median model, aims to minimize the total travel distance in the area while taking into consideration an exogenously determined number for telecenters. These models have different priorities and this study discusses their varying results.

This thesis is composed of five chapters and the first chapter is introduction. The second chapter has the background information about the digital divide between urban and rural, the telecenters and their role for rural areas. The third chapter explains the previous studies aiming location optimization. The fourth chapter involves the application of selected optimization models for the study area and their comparative results as well as providing explanations about the models and the data. And the last chapter has concluding remarks.

CHAPTER TWO:

Telecenters and Rural Development

2.1 Digital Divide and Rural Areas

The main purposes of ICT[1] use are to increase productivity, to create more value and to enhance transparency and participation. And to achieve them, all the actors in the society, which are the government, enterprises and citizens, should utilize ICT, their use should focus on value added electronic services and the digital divide should be reduced.

World Summit of Information Society, which was organized by United Nations (UN) and International Communications Union (ITU) as a two-step Summit in 2003 and 2005, emphasized the common will of all the participating countries to eliminate digital divide. In Article 14 of its Declaration of Principles, it is said that "We are resolute to empower the poor, particularly those living in remote, rural and marginalized urban areas, to access information and to use ICTs as a tool to support their efforts to lift themselves out of poverty".

While the studies to become an information society has been prolonging since 1990s, in Turkey, digital divide still exists by age, gender, education, profession, regions or by urban-rural. According to the results of 2012 ICT Usage in Households Survey[2], both computer and internet usages are twice more in urban than in rural (Table 2.1)[3]. By gender, the very well known fact that women utilize ICT less than men do is even worse for rural areas. Purpose of internet use that can provide us with

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[1] ICT is any kind of hardware or related system including technologies that is used to produce, store, arrange, manage, transfer, change, upload or download information in different environments. ICT denotes both computer and communication technologies, and means information technologies network.

[2] For the population aged 16-74.

[3] These figures illustrate the usages at any time within the last year before the survey was undertaken.

an idea of how efficient people utilize internet is also another issue and as can be seen from Table 2.2 below, people in urban areas utilize ICT in a more qualified and deliberate way than people in rural areas do[4].

Table 2.1. Computer and Internet Use, 2012 (%)

	Turkey	Urban		Rural	
		Male	Female	Male	Female
Computer	48.7	68.0	47.7	37.8	18.0
Internet	47.4	67.0	46.3	37.1	16.3

Table 2.2. Purposes of Internet Use, 2012 (%)

	Turkey	Urban	Rural
Making a health appointment with a practitioner via a website	19.6	21.5	9.5
Using online services related to travel or travel related accommodation	18.9	20.8	9.2
Selling of goods or services, e.g. via auctions	7.2	7.8	4.0
Internet banking	17.1	18.4	10.1

As of 2010, the ratio of the population covered by any wideband internet technology infrastructures, except mobile technologies, in Turkey is almost 90% (State Planning Organization, 2011a). On the other hand, Table 2.3 provides us with the relevant data showing the availability of technological infrastructure at home. According to these, ratio of households having computer and internet differs between urban and rural favoring urban areas.

[4] This question was asked to people who declared that they had used internet within the last 3 months before the survey was undertaken.

Table 2.3. Households with Computer and Internet, 2012 (%)

	Turkey	Urban	Rural
Personal Computer	31.8	38.2	16.3
Portable Computer (laptop, tablet, etc.)	27.1	33.5	11.8
Internet Connection	47.2	55.5	27.4

These lower ratios for having or using ICT in rural areas are because of several reasons. One of them is that rural inhabitants are not aware of the benefits or even the existence of such technologies. The insufficient internet infrastructure provision in rural areas, which is supposed to be provided mostly by public sector, is a technical barrier. Another reason is their low income that may cause not to afford to purchase a computer or have an internet connection at home. More importantly, digital content appropriate for rural inhabitants is not enough, therefore those people don't have a motivation to access or use the internet.

By definition in Turkey "rural" refers to the areas with a population of less than 20,000 and it is not homogeneous because it includes settlements with varying physical sizes[5]. By 2012, rural population corresponds to 27.7% of total population, which is 20.9 million, and 57% of it live in villages. It can easily be said that ICT usage is even worse in villages than rural in general and there is a need for more studies to be undertaken to make those more disadvantaged people in smaller settlements get benefit of ICT.

[5] There are 918 districts and 34,340 villages.

2.2 Benefits of ICT Use in Rural Areas

As rural inhabitants become ICT users, they will have more opportunity to reduce their disadvantages and raise their living standards. However, if they cannot, they will become more disadvantaged than even before. Thus, the use of ICT in rural areas will support rural development, which gives rise to an increase in rural living standards and income, while it reduces the digital divide between urban and rural, which contributes to the realization of the network effect[6]. Although it is hard to predict the amount of the value to be created in the economy by the use of ICT in rural areas, productivity increase in rural enterprises led by ICT diffusion and the network effect in general are enough to support it.

As the rural settlements are sparsely located in Turkey, it has been difficult to provide all these settlements with any kind of necessary physical and social infrastructure so far. Although there is not a proper dataset in Turkey, it is well known that ICT infrastructure is not sufficient in rural areas. The most dedicated effort in this regard has been undertaken by the Ministry of National Education to provide rural schools with internet connection. Once the school is connected to the internet, we can admit that this village has been covered. And, by 2009, 94% of primary school students and 100% of high school students had access to internet (either DSL or VSAT) at their schools (State Planning Organization, 2010). However, here we should take into consideration that not all the villages have a primary school in use and also high schools are rare at village level.

Usually people living in rural areas have less opportunity to keep up with new technological developments. Even though they become aware of them, their demand is being low because these technologies are expensive and difficult to understand or to

[6] Implies productivity increase by means of society-wide use of ICT.

use. The need for continuous technical support and also the security issues on the internet make these technologies more complicated and even dangerous for users who don't have any technical knowledge. Therefore, the most convenient way to make rural inhabitants gain ability and have opportunity to utilize ICT is to establish telecenters in rural area. Telecenter.org, a global network of people and organizations aiming to increase the social and economic impact of telecenters around the world, defines telecenter as a public place in which people can access ICT to find information, create, learn and communicate with others while they develop essential digital skills. Such an aggregated solution creates also a demand for digital content regarding local needs, which hardly occurs without its existence.

2.3 Telecenters in Use

Turkey declared its willingness to reduce digital divide in the Information Society Strategy (2006-2010) and telecenters were introduced formally as Public Internet Access Points (PIAPs), one of the initiatives aiming to reduce digital divide, by both the Information Society Strategy and its attached Action Plan. They were defined as the places where disadvantaged people in the society could access and use ICT. Those places had two functions as ICT training place and a place where people could get assistance to use internet and electronic services. The intention was to establish them in the areas where mostly disadvantaged people live.

However, in practice this initiative could not fulfill its mission. Of the 4,500 planned ones, 1,850 PIAPs could be established during 2006-2010 period in some training centers, libraries, barracks, etc. but those places were usually insufficient to serve people who really desired them. They were also underutilized because they were supposed to be open for 12 hours a day (Ministry of Development, 2013a).

During that period, some efforts were put by the private sector as well. Turk Telekom, the largest landline phone operator, established 850 telecenters by itself; that is, one telecenter in 850 districts. Moreover, municipalities have established telecenters total number of which is uncertain. Although municipalities are more successful in the management of these centers due to their flexible system, there is not an objective evaluation about their operation.

2.4 Suggested Telecenter Models in Turkey

To facilitate the realization of the action item about the establishment of PIAPs throughout the country, another study was undertaken by Middle East Technical University (METU) e-Government Research and Implementation Center. In this study, telecenter experiences from different parts of the world were examined and four telecenter models for Turkey were proposed as kiosk, mobile, mass use and mini model.

Kiosk model is for ICT use only. They are located at huge gathering places such as airports, train and subway stations, seaports, hospitals, shopping centers, tourism centers or bus stations and they should be placed in one or more distinct parts of the buildings. They can be of two types: 5-20 computers located next to each other or standard off the shelf kiosks distributed.

Mobile telecenter is a solution for hardly accessible areas where establishment of a permanent telecenter is very difficult or getting service from a telecenter located closeby is almost impossible. These mobile telecenters visit the settlements periodically so that people can have opportunity to use such technologies. Moreover, this mobile solution is a good way to increase awareness in the public and introduce new technologies. In a mobile telecenter there can be 4-10 computers together with peripheral units.

Mass use telecenters are established usually at the buildings of public institutions, non-governmental organizations, schools, lodgings or small / organized industry zones and are for both ICT training and ICT use. These places are very important in terms of distance learning, life long learning and vocational training, all of which aim to get participants have occupational and professional skills leading to social and economic development of the society. They include 5-20 computers and also peripherals units. In terms of size and location, current telecenters in Turkey are of this type.

Mini telecenters are established in rural areas and they aim to serve other villages in close vicinity as well as the village they are located in. In other words, villages are grouped and then served by one of them called hub, having a mini telecenter with 1-5 computers and peripheral units. Depending on their capacity they are used for only ICT usage or both ICT usage and ICT training. As well as those centers, information technology classes in schools, if available, can be made open to public when it is not used for educational purposes. This is important to be able to get maximum benefit from the existence of internet infrastructure once it is made available to the village.

2.5 Rural Telecenters and Rural Development

In telecenters people can get help about these technologies, without which they may hesitate to use them because of lack of self-confidence and low education levels. This is a very cost effective solution and also it supports a two-way interaction between rural and outer worlds. While rural inhabitants are consumers for outer world, outer world provides rural inhabitants with so many opportunities they have been unaware of before.

Establishment of rural telecenters is composed of three main efforts as the provision of internet connection to the settlement, the development of electronic services on the internet and the determination of telecenters' location.

2.5.1 Internet Connection

The necessity for the quality and fast internet service is the wideband internet connection and the best way to provide it is to use fiber cable which is the most expensive solution at the same time. On the other hand, because of the low demand there, any kind of internet connection in rural areas let alone fiber cable connection can be subordinate for either public or private sectors. Therefore, in those low demand areas alternative wideband internet connection technologies, such as Digital Subscriber Line (DSL), power line, Third Generation (3G), Global System for Mobile Telecommunications (GSM), Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX) or Very Small Aperture Terminal (VSAT) should be promoted.

2.5.2 Electronic Services

As the cost of these technologies have decreased as a result of very rapid progress and innovations, their use have been widened into unprecedented areas such as rural focused applications. Electronic services are the most important thing to make telecenters useful for rural inhabitants. To realize and accelerate rural development, electronic services can be offered in the fields of education, health, governmental issues, agriculture, alternative job opportunities and financial resources (Asik, 2009).

Education:

In Turkey, there has certainly been a progress in the ratio of enrollment while quality of education is still questionable throughout the country. Under these circumstances, ICT can contribute formal education in two ways: To increase online access to formal education in rural areas and to improve the quality of education in general. Furthermore, informal education is a convenient alternative to make human resources more qualified. Especially in rural areas the labor force needs to be enhanced through life long learning[7] so that people can become more employable.

ICT-supported education never replaces a teacher, however, it compensates the disadvantages caused by the difficulties to employ experienced and enough number of teachers in rural areas. It also helps instructors in teaching. Digital curriculum, ICT supported new teaching tools and methods, and digital networks pave the way to have fairer and higher quality education everywhere. Distance learning[8] is a big opportunity for people who could not or cannot reach education and also to have educated and skilled labor force. e-Learning[9] is a good alternative provided that demand oriented education programs are available on internet.

Health:

In Turkey, the quality and quantity of health service is not the same in urban and rural, or in all regions. Also, the fact that first stage health centers are not preferred by citizens as much as desired leads to higher costs and over-demanded health services at higher levels such as hospitals.

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[7] Any kind of learning activity to improve knowledge, interest, skills and abilities at any period of lifetime.

[8] The education process where learner and instructor from different places meet through various communication technologies.

[9] Distance learning supported by ICT.

e-Health[10] becomes a good opportunity for rural areas to get rid of their disadvantages in getting sufficient health care. The basic use of ICT in health is certainly the databases where personal, clinical or administrative data are stored. Such databases is the core for the delivery of health service, to have a proper diagnosis and consultancy regarding patients' health history as well as being very useful for decision makers about health related issues. ICT facilitates data collection in rural areas where reliable and up-to-date health information usually does not exist. Medical staff working especially at the first stage health service facilities can collect data about cases as they meet public frequently. This provides a critical input for databases and is also very useful to control epidemics and other illnesses.

It is possible in both urban and rural areas that people can find health related information on internet and get health appointment via phone or web. Medical staff can search medical publications, transfer medical registries, documents or images, join online discussions or video conferences, participate in surgeries or conduct consultancies from distance and monitor patients having ongoing treatment at home. In this regard, telemedicine[11] is of great importance to get clinical services and consultancy to rural areas. Similar to education, ICT can have a complimentary role for inexperienced physicians and other medical staff who need assistance and help from seniors to treat and lead patients or to use medical equipment.

Interaction with the Government and e-Governance

Government services are provided through the branches of public institutions in provinces and districts of Turkey[12]. Rural inhabitants, mostly the villagers have to

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[10] Use of ICT for the delivery of health care equally to all citizens and to improve the quality of health service.
[11] Provision of health service from distance.
[12] There are 81 provinces and 918 districts in Turkey.

travel to those centers by spending money and time to get the service. Furthermore, in case the registries and the procedures in the public institutions are not good enough, people have to wait there while sometimes they may even have to visit them more than once by spending time and money repetitively. This situation creates both financial loss and unhappiness for rural inhabitants. Establishment of new branches in small settlements might be suggested as a solution but this would be very costly for the government as the demand there is very low. Citizens need transparency and rapid responses while they deal with the government.

Through e-government[13] services, citizens spend less time and effort to find correct institution to have their work done, and as the more back office integration among public institutions comes to the ground, the easier the procedures become. This means even for the people living at distant points, it becomes possible to access and use governmental services easily without wasting time and money. There are also some electronic services aiming to make citizens participate in public administration. Through such services, rural citizens who have had very little influence on their own life so far become a part of the decision process. As a result, their control on their own life increases and this leads to an improvement in their self-confidence and life standards.

Agriculture

Although agriculture is the dominant economic activity in rural Turkey and 24.6% of the total employment still generates in that sector, its share in Gross

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[13] The provision of public services effectively, faster, easier and in a more transparent way. e-Government can be classified as Government-to-Citizen (G2C), Government-to-Business (G2B) and Government-to-Government (G2G). Two things are needed to get benefit from e-government services in a full context: back office integration between public institutions and citizen-focused applications.

Domestic Product, which was 7.9% by 2012, holds its low level. This situation necessitates some efforts supporting agriculture to increase its competitiveness and the income of rural inhabitants consequently.

In the agricultural sector there are two types of producers: large-scale producer, gaining high profit by accessing technical information, market and financial resources, utilizing machines, and small-scale producer, producing mostly for survival with very little access to information or opportunities. The latter case dominates the agricultural sector. As a result of high employment within the agricultural land that is at its largest and natural extent, farm sizes are small. As agricultural parcel sizes are far from being optimum and also parcels are dispersed and many, there is low efficiency in agricultural production.

Agricultural sector is not market oriented and it has long, complicated, unorganized and ineffective marketing channels. There are so many middlemen taking active role in the marketing of agricultural products especially for non-local markets and this makes most of the producers passive in the marketing process. Therefore, producers cannot produce regarding market dynamics, sell their products at good prices or earn as much money as they deserve. There is also a need for strong agriculture-industry connection.

Agriculture is directly linked with the human health as it is the food source of population, and also with the environment as it consumes natural resources and may harm nature with the (overdose) use of some inputs such as pesticides and fertilizers. As an alternative, good agricultural practices aim to preserve natural resources, protect health of humans and animals and track agricultural production process to ensure the standards. Farmers require knowledge or consultancy to do it and especially small-scale producers have the flexibility to adjust their production to such market needs once they know it.

Technology can be used in agriculture intensively for planning and monitoring the production, marketing the products (e-commerce), accessing technical information and tracking the production process for ensuring the use of those standards. Some information systems are also needed for administrative issues such as determination and allocation of aids and subventions by the government as well as establishment of early warning systems and decision support systems.

Alternative Job Opportunities

Both low level of the value created in agricultural sector and the shortage of alternative job opportunities in rural area lead to low income and poverty in those areas. The poverty ratio in rural area was determined as 38.7% in 2009, while it was 18.1% countrywide (Ministry of Development, 2012). Higher unemployment ratio, low income and poverty, all encourage migration from rural to urban, leaving less qualified and elderly people in rural. On the other hand, people who migrate to urban areas encounter similar problems there, as their skills do not match urban job market. Therefore, we need to improve the skills of human resources and also increase job opportunities in rural areas.

ICT can contribute creation of new job opportunities in four general ways: Use of e-commerce to promote, market and sell (non-agricultural) local products, which turns the potentials into account; shifting some ICT-based low qualified works like call centers to less developed areas such as rural; managing or working at telecenters to be established; working at to-be-established new enterprises that will be attracted by the improved ICT infrastructure in rural.

Access to Financial Resources

Existing financial resources usually do not cover low-income families or small enterprises because of the barriers like difficulty in physical access to even closest branch of a financial institution, inability to get necessary legal documents from public institutions, being ineligible for a credit or the cost of application itself.

Internet is an efficient tool for those low-income families or small enterprises to be able to get information about the variety and availability of financial resources. This is easy, cost-effective and not time-consuming way to do it. As long as financial institutions have appropriate financial resource alternatives for those, financial resources can be made more accessible for poor by offering online application option and mobile solutions, both of which reduce application costs.

2.5.3 Location of Telecenters

As rural settlements in Turkey are dispersed and sometimes there are physical and topographic barriers to access them, provision of governmental or public services becomes hard and costly. For this reason, National Rural Development Strategy aims to determine some rural "service settlements"[14] where those services will be provided (State Planning Organization, 2007). Such an approach has been in practice by Ministry of Health and Ministry of National Education. These ministries prefer to have their service provision in select villages and employ staff only there. Thus, people living around visit the health centers or they send their children to the schools there. Similarly, telecenters can be established in some settlements called hubs that will serve both itself and the other villages around. Hub can be either a village or a district center.

[14] Defined as the settlements with potentials to develop and with capacities to serve other villages around.

Telecenters help compensate the disadvantages rural inhabitants have as a result of their out-of-the-way location, insufficient infrastructure and low income. Also, the Tenth Development Plan (2014-2018) emphasizes that rural population's access to ICT services should be strengthened. Therefore, although there is not an Information Society Strategy and related Action Plan being implemented currently and promoting telecenters, regardless of such an initiative, telecenters are still needed in rural areas and should be established in such service settlements.

2.6 Challenges of Telecenters

Although there is a strong willingness to establish telecenters, keeping them operational is quite difficult especially in rural areas. Asik (2009) defined critical issues about the establishment and sustainability of rural telecenters as; (1) selection of the hub (settlement), (2) internet connectivity and electronic services offered, (3) management and (4) financial sustainability of telecenters.

2.6.1 Selection of the hub (settlement)

There are some suggestions for the villages where telecenters can be established.

1. Population: Population size is the most important factor as it is an indicator that the settlement has a core non-negligible demand for the telecenter by itself. In other words, the village itself can generate a proper level of demand with that population and dynamism.
2. Population structure: Usually this is satisfied if there is a large population in the settlement, however, it is good to emphasize again that the settlement should have a young and dynamic population structure, which is one of the indicators

that the settlement is not shrinking. Whether the inhabitants of the village desire to participate in such a challenging initiative or not is crucial as well because realization of the development requires strong willingness of the public.

3. Economic activities: If the settlement lacks a pushing economic factor, the telecenter would lose its importance because it is a knowledge center for producers to access crucial production and marketing information. Therefore, having an economic activity in the settlement leads to the frequent use of the telecenter and contributes to its sustainability.
4. Facilities: There are facilities such as primary schools or first stage health centers in some villages. One of them or both may exist in a village and inhabitants of the villages around lacking such facilities travel to that village to get the services. This is the same approach as the one suggested for telecenters. If there is a primary school or health care center in a village, that village has an advantage to be a hub because school or health care center also can take advantage of the internet connectivity brought for the telecenter, or vice versa.
5. Internet infrastructure and vacant places: If there is already an internet connection in the village regardless of its being actively used or not, this means saving time and money to be spent to have internet at the telecenter. Similarly, availability of vacant places to be turned into telecenters is preferable. Characteristics desired for such places are being located in the central part of the village, owned by public or the government and accessible by females, elderly and handicapped as well. Thus, existence of internet infrastructure or suitable vacant places make the village advantageous.
6. Location of the village: Inhabitants of the other villages to be served should reach the hub easily. For this, village should be on a main road for ultimate vehicle accessibility and should not be located on a rough terrain.

Some of the information sought regarding the suggestions above, such as vacant places in candidate villages or observations about public perception about telecenter, needs a study visit beyond obtaining data from institutions or analyses.

2.6.2 Internet Connectivity and Electronic Services

Issues about internet connectivity and electronic services are discussed in 2.5.1 and 2.5.2. Once internet connection is provided to the village, internet can be made available to school, health center and also the post office immediately. If the demand for electronic services is very limited or so low, then the internet connection in those places may be enough and no telecenter is required.

2.6.3. Management

As mentioned before, digital content is very important for the efficient use of telecenters. There are many different actors dealing with rural development and for that reason there is a need for a strong cooperation between institutions to develop and serve rural focused electronic services. Therefore, every stage of the process from the selection of telecenters' location to the management of them and the upgrade of services requires rigid planning and solid implementation. Thus, a managing organization should be proposed at both local and higher levels to have good coordination and integration.

2.6.4. Financial Sustainability

Another vital necessity is the need to develop public-private partnership models to sustain these centers. Compared to their operational cost, infrastructure cost is small and there are even non-public institutions willing to pay for their establishment[15]. On the other hand, to meet the financial requirements during their operational period, it is necessary to raise the demand for or the revenue of these telecenters so that they can be kept operational. Not only costs but also other uncommon issues such as flexible and long working hours which make it hard to employ a public official there require new approaches where public and private sectors share responsibilities. Public sector can establish all or some of the telecenters, do its best to have some digital content -as required by laws- developed and also coordinate different institutions from different sector, while leaving all other detailed issues to private sector or NGOs. Those things are too local to handle for central or even local governments and also such an approach can create new jobs and entrepreneurial opportunities for local people.

Establishment and operation of telecenters require so much money and effort. One may ask the social and economic benefits obtained in return to them. However, it is really hard to determine the exact value of those benefits as social returns are not measured and some benefits are not traceable. Even so it is good to have some mechanisms to monitor the process and collect data as much as possible.

Among the critical issues about telecenters, determination of the location of hubs can be analyzed using optimization methods. The integration of the criteria that can be used for hub selection into optimization problems can also be considered.

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[15] Estimated investment cost for the telecenter having only one computer is 1,385 TL and for the one having five computers is 7,230 TL. Costs include computers, peripheral equipment, networking and UPS. Annual operational cost for the telecenter having three computer, on average, is 12,000 TL. Costs include personnel, internet and telephone subscription, electricity, technical upgrading and maintenance and other minor revenues. (Asik, 2009; as of 2009 US$1=1.4098 Turkish Liras (TL))

CHAPTER THREE:

Literature Survey for Location Optimization

Location modeling aims to find the best location(s) to establish one or more facilities and operations research has been used for this purpose widely for a long time.

Daskin (2008) explains four areas of facility location models as analytic models, continuous models, network models and discrete models. He says analytic models, which are the simplest of all, assume that demand is distributed in some way over a service area and the facilities can be located anywhere there. Continuous models, however, assume that demands appear only at discrete points. The third branch, network models assume that both demand and facilities can only occur on a network composed of nodes and links. Often, demands occur only on nodes while facilities can be anywhere on the network. In the fourth and final branch, discrete location models, demands generally arise on the nodes and the facilities are restricted to a finite set of candidate locations, where distances or costs between any pair of nodes generally follow some rule while they may be arbitrary also.

He further classifies discrete location models to three broad areas as covering-based models, median-based models and other models. Covering-based models, which are utilized when the maximum distance between facilities and customers is more important than is the average distance, assume that demands need to be served within a coverage distance or time, and three prototypical models within this class are the set covering model, the maximal covering model and the p-center model. When a service is defined by the average distance between the facility providing the service and the customer being served in a location problem, median-based models minimizing the demand-weighted average distance between demand nodes and facilities assigned are used. They are of two types: the p-median model and the uncapacitated fixed charge location problem. Finally, the models, which do not fall into either of these categories, such as p-dispersion model maximizing the minimum distance between any pair of facilities, are among the other models.

Among covering based models, absolute 1-center weighted problem was defined and solved by Hakimi in 1964. He also formulated the p-center problem and appears to be the first to define an absolute median problem. Set covering problem was first introduced by Toregas in 1970 and Church and Revelle formulated maximal covering location problem in 1974.

P-median problem is to minimize the total weighted travel distance in a network where each demand node is served by its closest facility by locating p facilities and this was first introduced by Hakimi. The points in the solution set, which minimize the sum of the weighted distances, are the medians of the network (Church and Revelle, 1976)

Daskin and Owen (1999) analyzed and compared covering based models. Three key factors in these models are the number of facilities, the fraction of demand that must be covered or served within the maximum distance, and the coverage distance itself. They said set covering model minimizes the number of facilities needed to cover all demand nodes within a specified coverage distance that is determined exogenously. However, this often ends up with the need to site more facilities than can be afforded. Also, this model cannot distinguish between large and small demand nodes. All the nodes are simply covered and the marginal value of the facilities that cover the least demand is often very small, as well. A way to circumvent some of the problems associated with the set covering model is the maximal covering problem aiming to cover as much demand as possible within an exogenously specified coverage distance using a fixed number of facilities. Another way relaxing the coverage distance was tried by Hakimi, leading to the p-center problem whose objective is to minimize the maximum distance between a demand node and the nearest of an exogenously specified number of facilities.

They also brought up a common issue for the set covering and the p-center models both of which aim to cover all the demand. Their solution is often extremely sensitive to the coding of the network and by adding just one node, even it has a negligible demand, an increase in the number of required facilities in the case of the set covering formulation, or an increase in the maximum distance in the case of the p-center problem may occur.

Covering based models which are set covering, p-center, p-median and maximal covering problems, have been used and analyzed in literature and it has been a fruitful area for researchers. Revelle (1991) defines the location set covering problem as the first of the emergency services covering models and describes the initial assumption of all of the covering models that follow as that siting occurs at positions on a road network and the areas of demand (nodes) require coverage. The location set covering problem searches for the answer to the question of "find the least number of ambulances and their positions such that all demands have at least one ambulance stationed to respond within a time or distance standard". Regarding the unaffordable levels of the service a new formulation had been considered to answer the problem of "given a limited number of ambulances, at what sites should the ambulances be placed so that the maximum number of people (or calls for service) have an ambulance stationed within the travel time standard".

Eiselt and Marianov (2008) studied an extension of the basic set covering model and softened the covered/not covered dichotomy by replacing it with gradual covering.

Dhookit (1999) used double set covering model to determine the most appropriate sites for fire stations in Mauritius. As a preparation, he produced a binary matrix from the travel time matrix by applying a threshold time value, which was 15 minutes. This matrix formed the base to write down constraints of the optimization problem. Among the settlements determined by this first optimization problem, he interpreted mostly demanded settlements and picked them as the ones where fire stations will be placed. Then he defined another set covering problem for the remaining settlements, by excluding already picked ones and the settlements served by them, with a smaller travel time. Picked settlements from the first problem's result and the settlements determined as optimum in the second one altogether constituted the settlements to set fire stations in the area. By doing so, he could intervene the set covering approach and replaced some of the settlements determined as optimum in the first stage.

Classical set covering problem requires that each demand is covered at least once. Multi level location set covering problem searches for the smallest number of facilities required to cover each demand more than once. Church and Gerard (2003) focused on the solution of multi-level location set covering problem assuming each site could be selected at most once. They said this approach makes sense for reserve site selection or personnel selection problem for inspection teams and for the case of emergency equipment, allowing placement of multiple units at a given location it can be more realistic.

Daskin and Owen (1999) introduced two new models in their study to fill the gap in the studies that had been undertaken until that time. They applied a partial covering p-center (PC-PC) model and a partial set covering model by allowing the coverage level to be exogenously specified. They found out that when they reduced coverage requirement from 100 percent, the models had become less sensitive to the network coding that is the addition of nodes with negligible demand did not impact the maximum distance or the number of the required facilities. Moreover, these models could form the basis for a logistics planning process where it might be impossible or uneconomical to serve all customers equally well as well as could be used to trace out the trade off between level of service and the fraction of customers served at that level.

Ozsoy and Pinar (2006) investigated the capacitated vertex p-center problem to locate p facilities and assigning clients. In the capacitated version, each client was identified with some quantity of demand and clients' assignment to facilities is constrained with capacity restrictions of facilities. To solve optimization problem they used an algorithm relying on solving a series of set covering problems using an off-the-shelf IP solver. During this process, they conducted an iterative search over the coverage distances and at each stage the algorithm set a threshold distance value as radius to see if it was possible to cover all clients with given number of or less facilities.

Berman and Drezner (2008) found a new formulation for the conditional p-median and p-center problems on a network. They described conditional location problem as locating p new facilities to serve the demand points while q facilities are already located. Therefore, a demand can be served either by one of the existing or by one of the newly determined facilities whichever is the closest facility to the demand, once the locations for new facilities are determined.

Karakaneva (2003) used a maximal covering problem in which she gave each demand point a priority value depending on its strategic and operational importance. Also, while she introduced both demand and candidate station points as binary, after the first step she treated demand points as general integer variables to vary the constraint parameters.

In reserve site selection study, Williams (2008) aimed to minimize the cost or the area of the reserve system and took into consideration controlling the distance between reserve sites. He used two distance-based criteria. The first one was a separation criterion requiring any two selected sites to be at least a specified distance apart. The second criterion was a combination of proximity and redundant representation of species.

Cochran et al (2010) addressed the utilization of prior information and sample data together to find the collection of subsets optimizing estimated predictive proportional coverage. They introduced a logical and helpful process for using sample data to formulate the maximal covering problem as an integer programming problem with also the use of prior information.

Synder et al (2004a) said that both the classic maximal covering location problem and its dual problem that is the minimal uncovering model were solved and studied in the past for reserve site selection. Many of these applications in the literature assumed that the eligible sites did not differ in size, quality, cost or land value, which led to the inclusion of a constraint limiting the number of sites that could be selected. In their study they applied one- and two-objective problems for reserve site selection, where two-objective problems represented a trade-off between the number of land systems covered and the total area of selected sites. They concluded that two-objective formulations performed consistently better than one-objective formulations in terms of average solution time, number of iterations and nodes.

Costello and Polasky (2004) defined reserve site selection problem as a stochastic dynamic integer-programming problem in their study where the aim of a conservation agency was assumed to maximize the number of species surviving at the end of the planning horizon. In this approach, sites were chosen sequentially because of the budget constraint and some sites were chosen after some of the threats of development were realized. They found out that a dynamic approach is realistic and generates different results about conservation priorities than does a static approach.

Another model for dynamic reserve site selection application was undertaken by Snyder et al (2004b). In this study they addressed the problem of selecting sites to be protected over time with the aim of maximizing species representation, with uncertainty about future site development, and with periodic constraints on the number of sites that can be selected. As they formulated a discrete, 0-1 integer optimization model using logic from the scenario optimization for 2-period only, the model could be solved using commercial software to determine the best of sites to protect immediately or next period depending on the observed development. They suggested that the 2-period formulation they used was consistent with the uncertain nature of future budget and site availability, and also it could be used in a sequential fashion consistent with the adaptive planning.

Rajagopalan et al (2008) formulated the dynamic available coverage location model to determine the minimum number of ambulances to meet the requirement that in urban areas 95 percent of requests should be reached in 10 minutes and in rural area in 30 minutes or less. They determine the minimum number of ambulances and their locations for each time cluster where demand pattern changes drastically while meeting the coverage requirements with predetermined reliability.

CHAPTER FOUR:

Location Optimization for Telecenters

4.1 The Model

Telecenters are established in some of the settlements called hubs and they serve all of the villages. Set covering, p-center and p-median models were selected to determine the location of hubs aiming to cover the whole demand in the area. The first approach aims to minimize the number of telecenters given a maximum travel distance while the second one aims to minimize the maximum distance between hubs and villages and the third one aims to minimize the total travel distance, given total number of telecenters to be established.

An important aspect in optimization problems is budget constraint. Almost in all problems that constraint is involved due to limited resources. This is very real indeed. In this study, however, it is out of concern. As discussed in the previous chapter, the investment cost of telecenter is something but not too much. Financially speaking it is the operating costs that matter rather than the investment costs. With the implementation of Information Society Strategy and its attached Action Plan, the Government of Turkey has showed its willingness and support to establish telecenters[16]. Since then telecenters have been established not only by public institutions but also municipalities, private sector or non-governmental organizations. During that period, rather than getting enough money from somewhere to establish them, the problem was the uncoordinated and repetitive efforts to establish

[16] To realize Action Plan, the Government had allocated budget during 2007-2011 period as declared in the Annual Investment Programs. By the end of the implementation period of the Strategy and Action Plan, about 47% of the expected budget for the relevant Action Item had been spent (State Planning Organization, 2011b).

telecenters. And, all these efforts were limited to bigger settlements or already served areas, leaving people living in villages or lower income neighborhoods out of access.

Moreover, it is very hard to anticipate the necessary budget for telecenters without knowing exactly how many telecenters are necessary in an area. As long as there is a study revealing the demand to use ICT and the number of telecenters satisfying it, no one can propose the correct amount for budget allocation. For that reason, instead of having a budget constraint in the optimization problem, the results of the optimization problem should be used as the base to prepare a telecenter establishment project.

Therefore, it is certain that there is not a problem to allocate resources because there is a strong willingness by either governmental institutions or other organizations to meet the establishment costs of telecenters. Determination of the optimum number of telecenters is important for the clarification of required budget. And, as a last contribution, rural telecenters may not require brand new computers; even second held computers could be sufficient in use and be a very cost-effective or costless solution.

4.1.1 Set Covering Problem Approach

Mukundan and Daskin (1991) have described the location set covering model as seeking the locations of a minimum number of sites so that all the demand within the specified time or distance is covered by at least one of these facilities. In other words, the problem solution provides us with the least number of facilities ensuring that each user finds service within the specified distances.

According to Daskin (2008), a set covering problem does not distinguish between nodes having large and small demands and this is the disadvantage of that approach. Although this is still the case, we may introduce demand sizes to the problem to determine the upper limit for the capacity of telecenters/hubs to be built because rural telecenters are limited to five computers at most.

Sankaran and Raghavan (1997) implemented integer programming to determine the location and long-run sizes of the bottling plants for a company importing and selling liquefied petroleum gas (LPG) to domestic users through a network of dealers. The distribution system they analyzed had two levels as bottling plants and dealers, and by optimally designing that system they determined both the location and sizes of the plants. In the problem formulation, they also used a constraint to ensure that the capacity of bottling plants had never been exceeded, as well as general integer programming constraints. In other words, there was an upper limit on the size of a plant to be built in each site. With a similar approach, while we try to minimize the number of hubs, we can limit hub capacity to a level that shouldn't be exceeded by the total demand of the villages to be served from there.

Therefore, a set covering problem to determine the minimum number of hubs is formulated as follows:

Min $\sum X_j$

s.t. $\sum X_j >= 1$ (1)

$\sum DP_i X_{ij} <= X_j * C^{max}$ (2)

$X_j \in \{0,1\}$ (3)

X_j 1 if a telecenter is established at j

0 otherwise

$X_{ij} \in \{0,1\}$ (4)

X_{ij} 1 if village i is assigned to j

0 otherwise

$\forall i \in I, \forall j \in J$ and $j \in H_{iX}$

where

I: Set of all villages (origin/demand nodes)

J: Set of possible hubs (destination)

DP_i: Demand in village i

C^{max}: Upper limit for the capacity of a hub

The objective function minimizes the number of destinations or hubs. Constraint (1) stipulates that each demand node must be covered by one or more sited hubs. Demand node i is covered by site j if the distance between the village and that possible hub (d_{ij}) is less than or equal to the accepted maximum travel distance (D^t). Thus we can define $H_i = \{j \in J : d_{ij} <= D^t\}$, which means H_i is the set of hubs that can provide service to demand node i and any particular demand point i must find cover within its set of H_i, as explained by Toregas and Revell (1972) . Constraint (2) stipulates that the capacity of hubs cannot be exceeded. Constraint (3) and (4) are the integrality constraints.

4.1.2 P-Center Problem Approach

Daskin (2008) says that the p-center model finds the smallest possible coverage distance, which enables every node to be covered. P-center problem is used for the cases in which a finite set of candidate sites is given. This model is also known as the minimax problem because it is formulated to figure out the maximum distance between any demand and its nearest facility. On a network, the absolute p-center model allows facilities to be located on the nodes and the links, however, the vertex p-center model ignores links and restricts sites to the nodes. Unlike the set covering model, weighting can be utilized for the p-center problem to include demand levels. If the unweighted p-center problem is addressed, then the solution tends to be in more central but less populous areas. Suzuki and Drezner (1996) explain the p-center problem as equivalent to covering a given area in the plane having p identical circles where facilities are located at the centers of these circles and circles have the smallest possible radius.

In this study the p-center problem is a vertex model as the telecenters will be established in some of the settlements/nodes. The p-center problem is as follows:

Min Z

s.t. $\sum X_{ij} = 1$ (5)

$X_{ij} - X_j <= 0$ (6)

$\sum X_j <= P$ (7)

$w_i \sum d_{ij} X_{ij} - Z <= 0$ (8)

$X_j \in \{0,1\}$ (9)

X_j: 1 if facility is allocated at j

0 otherwise

$X_{ij} \in \{0,1\}$ (10)

X_{ij}: 1 if demand node i is assigned to hub j

0 otherwise

$\forall i \in I$ and $\forall j \in J$

where

Z: Upper bound on the radius of the feasible solution.

I: Set of all villages (origin/demand nodes)

J: Set of hubs (destination)

d_{ij} : The distance between demand node $i \in I$ and the hub $j \in J$

w_i: Demand coefficient

P: number of facilities to be located

The objective function aims to minimize the radius, that is the maximum distance between any demand node village i and its closest hub j. Constraint (5) stipulates that each village is assigned, (6) limits assignments of villages to selected sites; that is, i can be assigned to j only if j is a hub, (7) states that at most P facilities will be located and (8) forces Z to be larger than the distance between the village and the hub it is assigned. The size of the demand can be included through this constraint using a weight (w) if desired. Constraints (9) and (10) are integrality constraints.

4.1.3 P-Median Problem Approach

Daskin (2008) explains that median based models minimize the demand-weighted or average distance between a demand node and the destination point it is assigned. Such problems are used for the distribution planning cases in which minimizing total transport cost is essential. While covering models, such as set covering, treat distances as binary, median-based models take into consideration the real distances. Thus, the p-median model, which is one of the median-based models, locates a given P number of facilities to minimize the (demand weighted) distance between demand node and the nearest facility. Church and Revelle (1976) say minimizing average travel distance is the same as minimizing total weighted travel distance. As the p-median problem uses average distance or time that is traveled by those who utilize the facilities, the smaller this quantity the more accessible the system is to its users.

In this study the p-median problem is as follows:

Min $\sum \sum w_i d_{ij} X_{ij}$

s.t. $\sum X_{ij} = 1$ (11)

$X_{ij} - X_j <= 0$ (12)

$\sum X_j = P$ (13)

$X_j \in \{0,1\}$ (14)

X_j: 1 if facility is allocated at j

0 otherwise

$X_{ij} \in \{0,1\}$ (15)

X_{ij}: 1 if demand node i is assigned to hub j

0 otherwise

$\forall i \in I$ and $\forall j \in J$

where

I: Set of all villages (origin/demand nodes)

J: Set of hubs (destination)

d_{ij} : The distance between demand node $i \in I$ and the hub $j \in J$

w_i: Demand coefficient

P: number of facilities to be located

The objective function aims to minimize the maximum (demand-weighted) distance between any demand node i and the hub j. The size of the demand can be included in the objective function through use of weight, w. Constraint (11) stipulates that each village is assigned, (12) limits assignments of villages to selected sites as hubs and (13) states that P facilities will be located. Constraints (14) and (15) are integrality constraints.

4.2 Data

The study area is the Saimbeyli district of the city of Adana, south of Turkey and includes 26 settlements in total, 25 villages and the district center (Figure 4.1). Village populations range between 130 to 1,500 and the main economic activity in the area is agriculture. The road, connecting the city of Adana to Kayseri and Sivas provinces passes through the district.

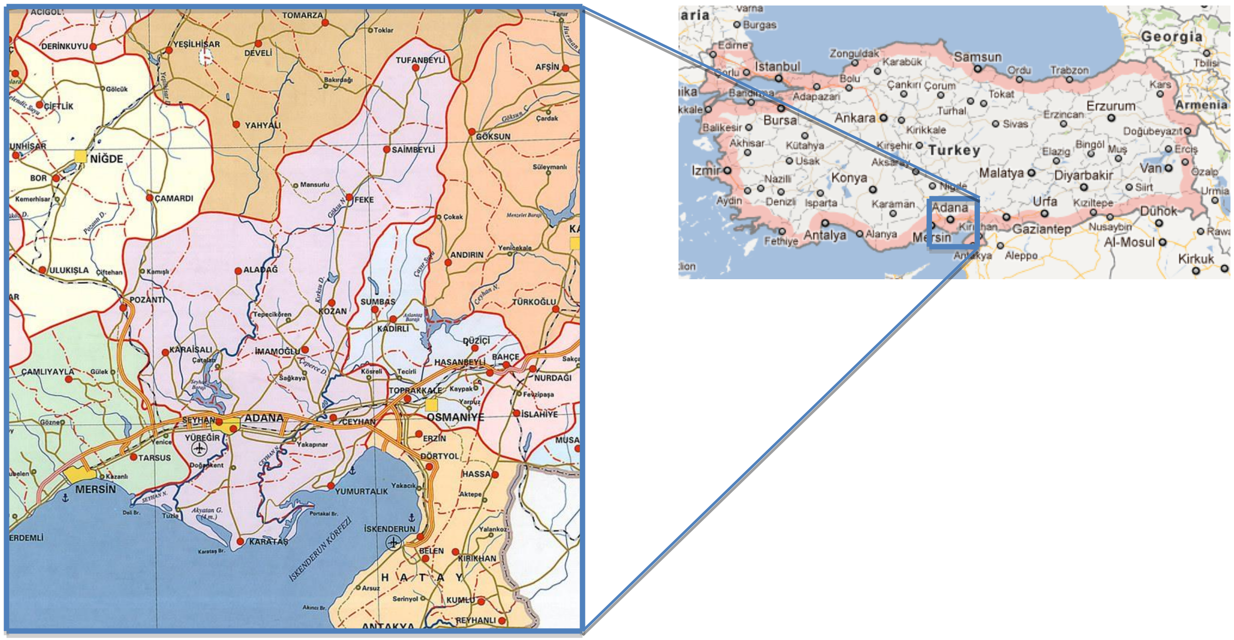


Figure 4.1 Study Area

The basic data required for the problems defined above are village populations, demand calculated from number of households in the villages and the distances between settlements.

4.2.1 Village Population

2012 population data obtained from Address Based Population Registry System, is given below (Table 4.1).

Table 4.1. Village Populations

	Village	Population
1	Cıvıklı	303
2	Cumhurlu	238
3	Eyüplü	470
4	Gürleşen	331
5	Himmetli	1156
6	Kandilli	553
7	Mahmutlu	367
8	Tülü	166
9	Yardibi	786
10	Çeralan	1148
11	Çatak	579
12	Çorak	256
13	Gökmenler	636
14	Kızılağaç	418
15	Naltaş	130
16	Karakuyu	1490
17	Değirmenciuşağı	368
18	Kapaklıkuyu	424
19	Ayvacık	415
20	Halilbeyli	194
21	Aksaağaç	1059
22	Topallar	135
23	Yeniköy	498
24	Avcıpınarı	131
25	Beypınarı	369

4.2.2 Demand by Villages

The best way to calculate demand is to use number of households (HHs). It will mostly be driven by the main economic activity in the village and the demand for telecenters will not be the same during the whole year. As in those villages it is agriculture that is the principal activity, we can assume that demand to use telecenters will be higher during spring, summer and fall seasons. The unused capacity during wintertime will provide a good chance to offer basic ICT training or some educational and vocational training programs for the public in telecenters.

In demand calculation we can assume that during the mostly occupied period, users visit telecenter twice a month, for two hours each time. Thus the equation is given as:

Demand per village = Number of HH x (2x2) = Number of HH x 4 hours/month

Calculated demand values by villages are provided in Table 4.2.

Table 4.2. Demand by Villages

	Village	**Number of HHs**	**Demand**
1	Cıvıklı	84	336
2	Cumhurlu	65	260
3	Eyüplü	70	280
4	Gürleşen	68	272
5	Himmetli	250	1000
6	Kandilli	60	240
7	Mahmutlu	125	500
8	Tülü	68	272
9	Yardibi	250	1000
10	Çeralan	300	1200
11	Çatak	110	440
12	Çorak	65	260
13	Gökmenler	209	836
14	Kızılağaç	230	920
15	Naltaş	60	240
16	Karakuyu	350	1400
17	Değirmenciuşağı	100	400
18	Kapaklıkuyu	85	340
19	Ayvacık	85	340
20	Halilbeyli	42	168
21	Aksaağaç	160	640
22	Topallar	45	180
23	Yeniköy	102	408
24	Avcıpınarı	90	360
25	Beypınarı	73	292

4.2.3 Distances Between Settlements

Shortest path distances between settlements derived from Google Maps are given in Appendix A.

4.2.4 Capacity of Hubs

Assuming that telecenters will be open to the public every day and operate for 12 hours, their service time per computer on a monthly basis can be calculated as given below:

Service time = 30(days)x12 hours = 360 hours/month.

Telecenters in rural areas are expected to have 1-5 computers. Thus, maximum telecenter capacity can be calculated using service time per computer as below:

Telecenter capacity= 360x5 = 1,800 hours/month

4.3 Solutions of Operations Research Problems

LINGO Version 8.0 was used to solve all problems.

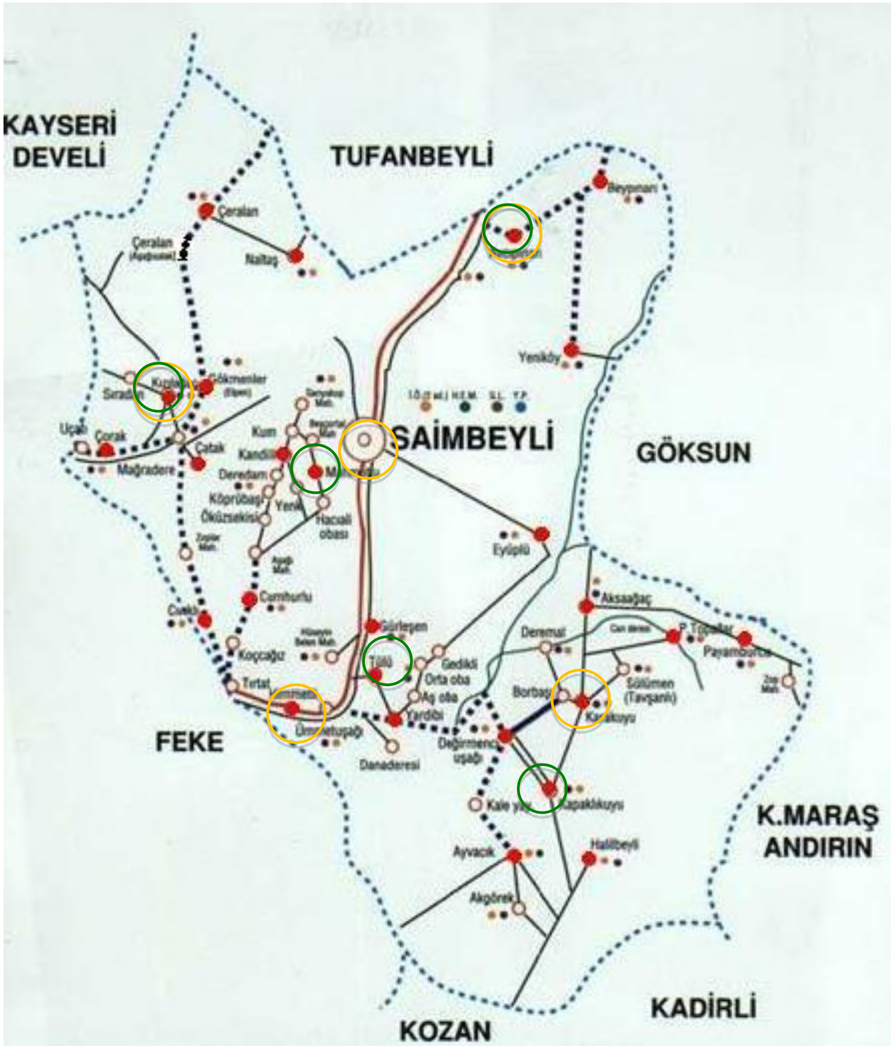
4.3.1 Set Covering Problem

The set covering problem requires defining subsets based on travel time or distance. In this problem, subsets for each origin point were defined based on the criterion that inhabitants in that village will not travel more than 20 km to reach a telecenter. On the other hand, there is not a subset for a district center as it can be a destination point only.

A 20-km distance is quite reasonable to travel in rural areas and also that distance creates a very convenient coverage area to group the villages around for this study site. For instance, we could hardly group villages based on 10-km distance, as they are mostly further apart from other villages than this distance. Travel distance can be different in some other areas depending upon village density.

The set covering problem formulation, where Y_i stands for X_{ij}, from the LINGO software is given in Appendix B. In the formulation, the purpose of the third constraint is to determine that the district center will be one of the hubs, assuming that village people prefer the district center to a village to get service as they believe that the district center has more facility and is more enjoyable. Also, no village falls within a 20-kilometer perimeter of the village of Naltaş and to define the subset of this village in the first constraint, the two closest villages are selected. The village of Naltaş is not defined within the second constraint at all because it is not suitable to be a hub and this is reflected in the third constraint, too.

The solution to the set covering problem ends up with five hubs. In other words, the objective function value is five. The hubs determined by the solution to set covering problem are the villages Himmetli, Kızılağaç, Karakuyu and Avcıpınarı as well as the district center Saimbeyli (Figure 4.2). This means that all 25 villages in the area will be able to get service from at least one of the telecenters that will be located in five hubs. If we didn’t have the third constraint, the hubs would be Mahmutlu, Tülü, Kızılağaç, Kapaklıkuyu and Avcıpınarı as shown in the Figure below.



Hubs determined without district center constraint

Hubs determined with district center constraint

Figure 4.2. Hubs Determined by the Set Covering Problem

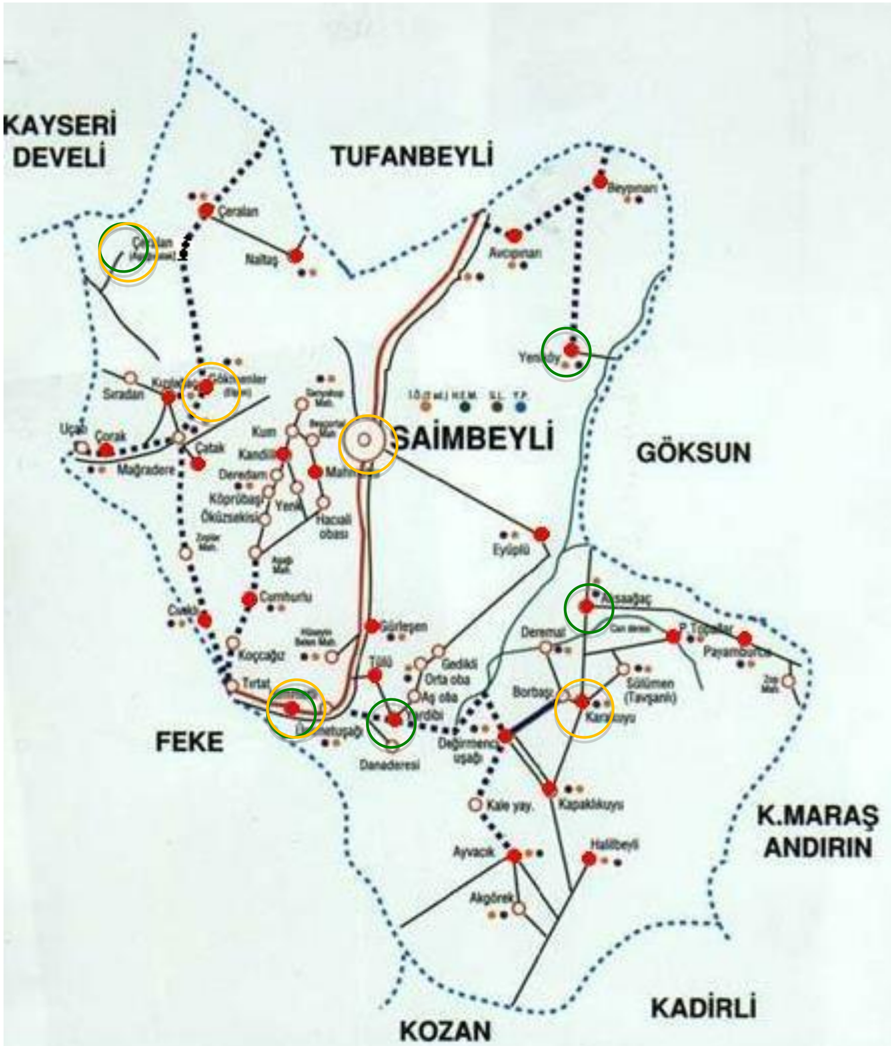
4.3.3 P-Center Problem

The p-center problem needs the number of telecenters to be established in the area to determine the minimum distance between the hub and the furthest village assigned to that. Elloumi et al (2004) say there is a strong relation between the p-center and the set covering problems in the general case. To test this we can define the number of hubs as five, which was determined by the set covering problem, and solve the p-center problem. As demand size is not important in this problem, w is set to 1.

The formulation of the p-center problem solved in LINGO software is provided in Appendix C, where Y_i stands for X_j. The objective function value is determined as 21.1 kilometers, and it is different from the pre-determined distance for the set covering problem, which was 20 kilometers. This difference is because of the village of Naltaş. None of the villages had fallen within 20-kilometer perimeter of it and two closest villages instead were selected as candidate hubs for that village while defining subsets. And 21.1 kilometers, which was determined by the p-center problem, is the distance between Naltaş and the closest village. Thus the p-center problem gives us the maximum distance we utilized in the set covering problem. The problem also results in that the telecenters will be located in Himmetli, Yardibi, Çeralan, Aksaağaç and Yenikoy.

The p-center model gives us a chance to form a preferred candidate hubs set. In this study the only criterion for the eligibility is the population size and regarding the population data in Table 4.1, nine villages having a population of more than 500[17] as well as the district center are selected as candidate destination points. In Appendix C, an additional fifth constraint stands to eliminate the villages that are not eligible to be a candidate. This makes the objective function value increase to 30.8 kilometers and in this case location of hubs is determined as Himmetli, Çeralan, Gökmenler, Karakuyu and Saimbeyli (Figure 4.3).

[17] As calculated from the data by the Ministry of Interior, the average village population size in Turkey is 358 and it seems appropriate to assume 500 as the minimum population for a hub.



Hubs determined without eligibility constraint

Hubs determined with eligibility constraint

Figure 4.3. Hubs Determined by the P-Center Problem

4.3.3. P-Median Problem

Similar to the p-center problem, the p-median problem approach requires total number of telecenters to be established in the area. One way to determine this number is to use total demand for telecenters in the area and the maximum capacity of supply by rural telecenters. Based on this, once we sum all the demands up and then divide this sum by the maximum telecenter capacity, we end up with seven telecenters as below. Alternatively, we can use number of telecenters determined by the set covering problem, which is five.

Total demand / Capacity of telecenter with 5 PCs = 12,584 / 1,800 ≈ 7

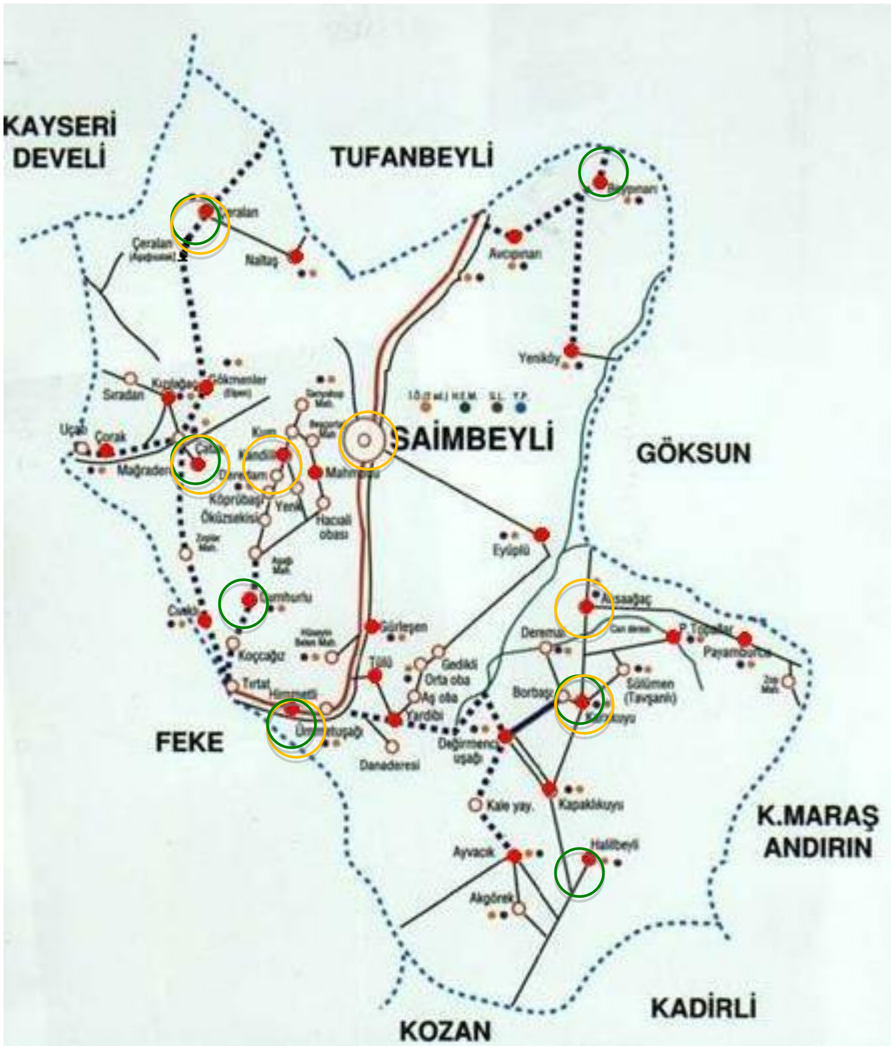
In the p-median approach, we have the option to limit the location of candidate hubs based on their comparative potentials. The same eligibility constraint used in the p-center problem can be used for this problem, too. The formulation, where Y_i stands for X_j, from the LINGO software is provided in Appendix D and similarly additional fourth constraint is to eliminate the villages that are not eligible to be a candidate.

As can be seen from Table 4.3 below, the minimum travel distance, which is the objective function value, increases when we decrease the pre-determined number of telecenters or when we want to establish telecenters in some select destination points based on the eligibility criterion.

Table 4.3. Results of the P-Median Problem

Number of Telecenters	Eligible Sites Used	Objective Function Value (km)	Hubs Determined
7	Yes	221.0	Himmetli, Kandilli, Çeralan, Çatak, Karakuyu, Aksaağaç, Saimbeyli
	No	146.7	Cumhurlu, Himmetli, Çeralan, Çatak, Karakuyu, Halilbeyli, Beypınarı
5	Yes	254.3	Himmetli, Kandilli, Çeralan, Çatak, Karakuyu
	No	189.3	Cumhurlu, Himmetli, Çatak, Karakuyu, Avcıpınarı

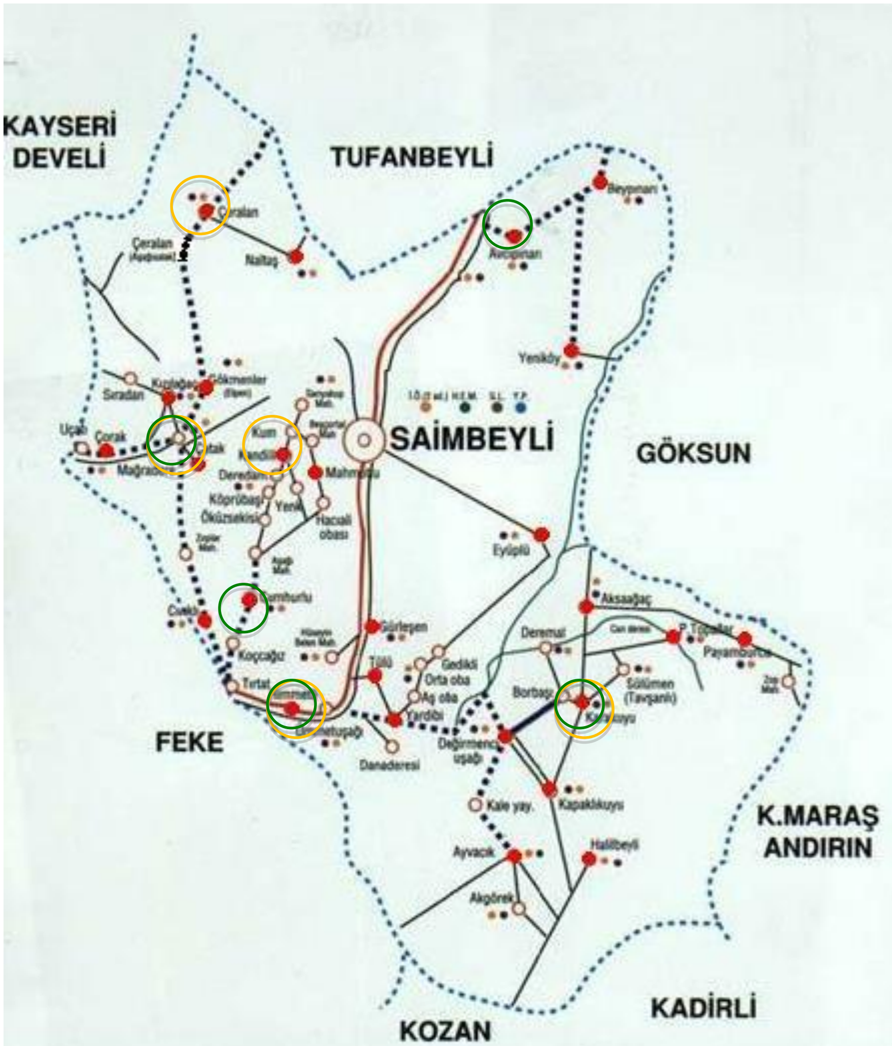
Figure 4.4 and 4.5 show the location of telecenters determined by the p-median model. Hubs are determined where villages mostly concentrate when we don't have any preferences for hubs. Thus, spatial distribution of hubs seems better when we don't apply eligibility criteria.



Hubs determined without eligibility constraint

Hubs determined with eligibility constraint

Figure 4.4. Hubs Determined by the P-Median Problem (P=7)



Hubs determined without eligibility constraint

Hubs determined with eligibility constraint

Figure 4.5. Hubs Determined by the P-Median Problem (P=5)

4.3.4. Comparison of the Results

The classical set covering problem aims to minimize the number of telecenters in such a way that at least one hub will serve the village, so that all demand in the area will be covered. Thus the solution provides us with the number and location of hubs but it does not address which village will be served by which hub. In problem formulation we can introduce identical or varying maximum capacity values for each candidate hub, however, as long as we aim to have villages to be served at least one of the hubs, we can't guarantee that the maximum capacity will not be exceeded. Therefore, the objective function value of the set covering problem here says that we can serve all the villages via five hubs, however does not say that their capacity will be limited to five computers, although it was a constraint. Otherwise the determined number of telecenters would be more than five, as the number of required telecenters to meet total demand based on five computers per hub has been calculated as seven.

The way to ensure such a limitation is to formulate the set covering problem such that each village will be served by only one hub. Karimi and Bashiri (2011) applied the set covering model in two distinct ways as a single allocation and multiple allocation set covering. In the former one they formulated the relevant constraint using "equal to one" instead of "greater than or equal to one" while the latter one was in the classical way. However, it is not always possible to have a feasible solution when we use such a strict constraint.

Just as in the case where we have pre-determined the district center as a hub, we can also determine a subset of eligible candidate sites regarding some specifications such as population size. However, similar to the previous case, it may not be possible to obtain a feasible solution.

Once the number of telecenters in the area is decided, the p-center problem determines the maximum radius of the hubs to cover the whole demand. This is a good method to assign demand points to serving points when we have already known the number of facilities. While doing so it aims to minimize the maximum distance between those serving points and the villages within its coverage area.

The p-median problem aims to minimize the total travel distance to reach the assigned hub from the village. As we are not dealing with personal travel times we did not apply a demand coefficient in the objective function although it was possible. The solution in this problem provides us with a total travel distance in the area, which can become more meaningful when we compare it with several other distance values obtained. Anyhow, the idea of the minimization of the travel distance itself was more important than its value.

The good thing in both p-center and p-median problems is that we can definitely determine the origin-destination pairs and the exact capacity requirement per hub. Moreover, we can introduce our preferred candidate destination points set to the problem. However, the pre-determination of the number of telecenters to be established in the area is not easy for either of them unless there is a policy / decision that has already declared that number or a relevant financial issue. Also, as we don't have a constraint regarding the maximum capacity of the hubs in the formulations, we can observe that total demand per hub is sometimes higher than the maximum capacity (supply capacity) of the hubs calculated in 4.2 Data part.

We can think about the combination of the set covering problem and either p-center or p-median problems. In other words, we can determine the number of telecenters needed from the classical set covering problem and then use it as the given number of facilities in other problems. Both problems relocate that number of points regarding different aims.

CHAPTER FIVE:

Conclusion

Starting with location-production theory, facility locating has been studied a lot. In many different fields such as locating emergency services or reserve selection for endangered species, optimum location points or coverage areas were defined using optimization techniques. There are several optimization models among which the user selects the most appropriate one.

Rural telecenters aiming to make rural inhabitants access and use ICT are necessary both to reduce digital divide and to accelerate rural development. However, there are some challenges to have well operating telecenters, and optimum location selection for them is one of the crucial issues.

Regarding the principle of having service centers in rural and the existence of low demand for ICT, determination of the hubs where telecenters will be located is the best approach to make ICT available in rural areas. Hubs can be either villages or district centers but they always serve a group of villages.

This study has tried three models as the set covering, the p-center and the p-median models. The set covering model used subsets of destination points defined based on the pre-determined maximum travel distance. The aim was to minimize number of facilities provided that each village would get service from at least one of the selected hubs. The model ended up with five hubs but did not provide information about origin-destination pairs. The p-center problem aimed to minimize the maximum number of travel distance between origin and destination pairs based on a given number of telecenters. When we had defined the number of telecenters to be the same as the number determined by the set covering problem, we ended up with the maximum distance value that had been used in the set covering problem. This close relationship between these two models can be analyzed further by using them back and fort where some preferences can be involved as additional constraints at each stage. This may also reduce the limitations of the set covering problem partially. The p-median problem provided us with total number of travel distance from villages to destination points given exogenously determined number of hubs. The minimized total travel time does not have a meaning in absolute terms in this study but different values obtained from the p-median problem using varying parameters can be compared. Similarly, use of this model together with the set covering problem may also be considered.

If there were no intention to use optimization methods, the logical way to decide those hub settlements would be to evaluate some characteristics of the settlements such as population size, economic activities in the settlement or the inhabitants' willingness to take part in such an initiative. Optimization models have a different approach but for all three models here it is possible to add new constraints reflecting our preferences about the characteristics of the settlements to the classical problem formulations to some extent. However, additional constraints may lead to infeasible solutions or lead to an increase in cost or travel time/distance.

The selection of the optimization model to determine location of telecenters depends on the priority of the decision maker. However, applying the set covering problem once is useful as it shows the total number of hubs in the area. This is a good starting point for further analysis or may even be enough in some cases.

In the study, some data were generated based on the assumptions because there aren't any operating rural telecenters yet. As rural telecenters become operational in Turkey, such data will become healthier and optimization problems will lead to better results. Based on the assumption data used in the models, either capacities or numbers of telecenters determined by the problems were higher than expected.

Optimization methods should be used for the determination of location of telecenters but there should be some efforts to specify the optimization problems to reflect our preferences also. The willingness of local people to be a part of such an initiative has especially critical importance and should be taken into consideration. The difficulty is that determining location of telecenters is not a straightforward decision, but rather a decision having social dimensions.

APPENDIX A

Distances Between Settlements

DESTINATION

ORIGIN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	0	5.3	27.2	16.7	11.4	14.2	12.4	14.6	17.6	27.8	12.2	17.3	15.4
2	5.3	0	28.4	18	12.7	10.9	9.2	15.9	18.9	33	17.5	22.6	20.6
3	27.2	28.4	0	12	16.2	36	35.6	15.7	22.4	54.9	39.4	44.5	42.5
4	16.7	18	12	0	5.8	25.5	25.2	5.3	11.9	44.5	28.9	34	32.1
5	11.4	12.7	16.2	5.8	0	21.6	19.9	3.6	6.2	39.2	23.6	28.7	26.8
6	14.2	10.9	36	25.5	21.6	0	7.8	24.7	27.8	41.9	26.4	31.5	29.5
7	12.4	9.2	35.6	25.2	19.9	7.8	0	23	26	40.2	24.6	29.7	27.8
8	14.6	15.9	15.7	5.3	3.6	24.7	23	0	9.8	42.4	26.8	31.9	29.9
9	17.6	18.9	22.4	11.9	6.2	27.8	26	9.8	0	45.4	29.8	34.9	33
10	27.8	33	54.9	44.5	39.2	41.9	40.2	42.4	45.4	0	15.6	20.7	12.4
11	12.2	17.5	39.4	28.9	23.6	26.4	24.6	26.8	29.8	15.6	0	5.2	3.1
12	17.3	22.6	44.5	34	28.7	31.5	29.7	31.9	34.9	20.7	5.2	0	8.2
13	15.4	20.6	42.5	32.1	26.8	29.5	27.8	29.9	33	12.4	3.1	8.2	0
14	14.7	20	41.9	31.5	26.1	28.9	27.1	29.3	32.3	18.1	2.6	6.3	5.7
15	48.6	53.9	58.8	48.4	52.1	50.5	58.3	51.6	58.3	21.1	36.3	41.5	33.3
16	31.3	32.6	36.1	25.6	19.9	41.5	39.7	23.5	19.6	59	43.5	48.6	46.6
17	22.3	25.6	27	16.6	10.8	32.5	30.7	14.4	10.6	50	34.6	39.6	37.6
18	36.6	37.8	41.3	30.9	25.1	46.7	45	28.7	26.9	64.3	48.9	53.9	51.9
19	26.2	27.5	31	20.5	14.8	36.4	34.6	18.4	19.6	54	38.5	43.5	41.6
20	33.3	34.6	38.1	27.6	21.9	43.5	41.7	25.5	26.8	61.1	45.6	50.6	48.7
21	39.9	41.2	44.6	34.2	28.5	50	48.3	32.1	28.2	67.7	52.2	57.2	55.2
22	43	44.3	47.8	37.4	31.6	53.2	51.5	35.2	31.3	70.8	55.3	60.3	58.4
23	56.6	57.9	52.3	41.9	45.6	44	51.8	45.1	51.8	39.1	54.3	59.5	51.2
24	43.7	45	39.5	29	32.7	31.1	39	32.2	38.9	26.2	41.4	46.6	38.3
25	50.4	51.7	46.1	35.7	39.4	37.8	45.7	38.9	45.6	32.9	48.1	53.3	45

DESTINATION

ORIGIN

	14	15	16	17	18	19	20	21	22	23	24	25	26
1	14.7	48.6	31.3	22.3	36.6	26.2	33.3	39.9	43	56.6	43.7	50.4	25.7
2	20	53.9	32.6	25.6	37.8	27.5	34.6	41.2	44.3	57.9	45	51.7	27
3	41.9	58.8	36.1	27	41.3	31	38.1	44.6	47.8	52.3	39.5	46.1	21.5
4	31.5	48.4	25.6	16.6	30.9	20.5	27.6	34.2	37.4	41.9	29	35.7	11.1
5	26.1	52.1	19.9	10.8	25.1	14.8	21.9	28.5	31.6	45.6	32.7	39.4	14.8
6	28.9	50.5	41.5	32.5	46.7	36.4	43.5	50	53.2	44	31.1	37.8	14.4
7	27.1	58.3	39.7	30.7	45	34.6	41.7	48.3	51.5	51.8	39	45.7	22.3
8	29.3	51.6	23.5	14.4	28.7	18.4	25.5	32.1	35.2	45.1	32.2	38.9	14.3
9	32.3	58.3	19.6	10.6	26.9	19.6	26.8	28.2	31.3	51.8	38.9	45.6	20.9
10	18.1	21.1	59	50	64.3	54	61.1	67.7	70.8	39.1	26.2	32.9	39.7
11	2.6	36.3	43.5	34.6	48.9	38.5	45.6	52.2	55.3	54.3	41.4	48.1	38
12	6.3	41.5	48.6	39.6	53.9	43.5	50.6	57.2	60.3	59.5	46.6	53.3	43
13	5.7	33.3	46.6	37.6	51.9	41.6	48.7	55.2	58.4	51.2	38.3	45	41.1
14	0	38.9	46	37	51.3	40.9	48	54.6	57.7	56.9	44	50.7	40.5
15	38.9	0	71.9	63	77.2	66.9	74	80.6	83.7	36.7	23.8	30.5	37.3
16	46	71.9	0	9	7.4	17.7	10.6	8.6	11.8	65.4	52.6	59.2	34.6
17	37	63	9	0	65.9	55.6	62.7	69.2	72.4	85.9	73.1	79.8	25.6
18	51.3	77.2	7.4	65.9	0	10.3	3.2	15.9	19	70.7	57.9	64.6	39.9
19	40.9	66.9	17.7	55.6	10.3	0	7.1	26.2	29.4	60.4	47.5	54.2	29.5
20	48	74	10.6	62.7	3.2	7.1	0	19.1	22.3	67.5	54.6	61.3	36.7
21	54.6	80.6	8.6	69.2	15.9	26.2	19.1	0	14.9	74	61.2	67.9	43.2
22	57.7	83.7	11.8	72.4	19	29.4	22.3	14.9	0	77.2	64.3	71	46.4
23	56.9	36.7	65.4	85.9	70.7	60.4	67.5	74	77.2	0	12.9	11.1	30.8
24	44	23.8	52.6	73.1	57.9	47.5	54.6	61.2	64.3	12.9	0	6.7	18
25	50.7	30.5	59.2	79.8	64.6	54.2	61.3	67.9	71	11.1	6.7	0	24.7

1 - Cıvıklı
2 - Cumhurlu
3 - Eyüplü
4 - Gürleşen
5 - Himmetli
6 – Kandilli
7 - Mahmutlu
8 - Tülü
9 - Yardibi
10 - Çeralan
11 - Çatak
12 - Çorak
13 - Gökmenler
14 - Kızılağaç
15 - Naltaş
16 - Karakuyu
17 - Değirmenciuşağı
18 - Kapaklıkuyu
19 - Ayvacık
20 - Halilbeyli
21 - Aksaağaç
22 - Topallar
23 - Yeniköy
24 - Avcıpınarı
25 -Beypınarı
26 - Saimbeyli

APPENDIX B.

Mathematical Formulation for the Set Covering Problem

```
MIN X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 + X10 + X11 + X12 + X13 + X14 + X15 +
X16 + X17 + X18 + X19 + X20 + X21 + X22 + X23 + X24 + X25 + X26

ST
1)X1 + X2 + X4 + X5 + X6 + X7 + X8 + X9 + X11 + X12 + X13 + X14 >= 1
  X1 + X2 + X4 + X5 + X6 + X7 + X8 + X9 + X11 + X14 >= 1
  X3 + X4 + X5 + X8 >= 1
  X1 + X2 + X3 + X4 + X5 + X8 + X9 + X17 + X26 >= 1
  X1 + X2 + X3 + X4 + X5 + X7 + X8 + X9 + X16 + X17 + X19 + X26 >= 1
  X1 + X2 + X6 + X7 + X26 >= 1
  X1 + X2 + X5 + X6 + X7 >= 1
  X1 + X2 + X3 + X4 + X5 + X8 + X9 + X17 + X19 + X26 >= 1
  X1 + X2 + X4 + X5 + X8 + X9 + X16 + X17 + X19 >= 1
  X10 + X11 + X13 + X14 >= 1
  X1 + X2 + X10 + X11 + X12 + X13 + X14 >= 1
  X1 + X11 + X12 + X13 + X14 >= 1
  X1 + X10 + X11 + X12 + X13 + X14 >= 1
  X1 + X2 + X10 + X11 + X12 + X13 + X14 >= 1
  X10 + X15 + X24 >= 1
  X5 + X9 + X16 + X17 + X18 + X19 + X20 + X21 + X22 >= 1
  X4 + X5 + X8 + X9 + X16 + X17 >= 1
  X16 + X18 + X19 + X20 + X21 + X22 >= 1
  X5 + X8 + X9 + X16 + X18 + X19 + X20 >= 1
  X16 + X18 + X19 + X20 + X21 >= 1
  X16 + X18 + X20 + X21 + X22 >= 1
  X16 + X18 + X21 + X22 >= 1
  X23 + X24 + X25 >= 1
  X23 + X24 + X25 + X26 >= 1
  X23 + X24 + X25 >= 1

2)336Y1 + 260Y2 + 272Y4 + 1000Y5+ 240Y6 + 500Y7 + 272Y8 + 1000Y9 + 440Y11 + 260Y12 +
836Y13 + 920Y14 - 1800X1 <= 0
  336Y1 + 260Y2 + 272Y4 + 1000Y5 + 240Y6 + 500Y7 + 272Y8 + 1000Y9 + 440Y11 + 920Y14 -
1800X2 <= 0
  280Y3 + 272Y4 + 1000Y5 + 272Y8 - 1800X3 <= 0
  336Y1 + 260Y2 + 280Y3 + 272Y4 + 1000Y5 + 272Y8 + 1000Y9 + 400Y17 - 1800X4 <= 0
  336Y1 + 260Y2 + 280Y3 + 272Y4 + 1000Y5 + 500Y7 + 272Y8 + 1000Y9 + 1400Y16 + 400Y17 +
340Y19 - 1800X5 <= 0
  336Y1 + 260Y2 + 240Y6 + 500Y7 - 1800X6 <= 0
  336Y1 + 260Y2 + 1000Y5 + 240Y6 + 500Y7 - 1800X7 <= 0
  336Y1 + 260Y2 + 280Y3 + 272Y4 + 1000Y5 + 272Y8 + 1000Y9 + 400Y17 + 340Y19 - 1800X8
<= 0
  336Y1 + 260Y2 + 272Y4 + 1000Y5 + 272Y8 + 1000Y9 + 1400Y16 + 400Y17 + 340Y19 - 1800X9
<= 0
  1200Y10 + 440Y11 + 836Y13 + 920Y14 + 240Y15 - 1800X10 <= 0
  336Y1 + 260Y2 + 1200Y10 + 440Y11 + 260Y12 + 836Y13 + 920Y14 - 1800X11 <= 0
  336Y1 + 440Y11 + 260Y12 + 836Y13 + 920Y14 - 1800X12 <= 0
  336Y1 + 1200Y10 + 440Y11 + 260Y12 + 836Y13 + 920Y14 - 1800X13 <= 0
  336Y1 + 260Y2 + 1200Y10 + 440Y11 + 260Y12 + 836Y13 - 1800X14 <= 0
  1000Y5 + 1000Y9 + 1400Y16 + 400Y17 + 340Y18 + 340Y19 + 168Y20 + 640Y21 + 180Y22 -
1800X16 <= 0
  272Y4 + 1000Y5 + 272Y8 + 1000Y9 + 1400Y16 + 400Y17 - 1800X17 <= 0
  1400Y16 + 340Y18 + 340Y19 + 168Y20 + 640Y21 + 180Y22 - 1800X18 <= 0
  1000Y5 + 272Y8 + 1000Y9 + 1400Y16 + 340Y18 + 340Y19 + 168Y20 - 1800X19 <= 0
  1400Y16 + 340Y18 + 340Y19 + 168Y20 + 640Y21 - 1800X20 <= 0
```

```
  1400Y16 + 340Y18 + 168Y20 + 640Y21 + 180Y22 - 1800X21 <= 0
  1400Y16 + 340Y18 + 640Y21 + 180Y22 - 1800X22 <= 0
  408Y23 + 360Y24 + 292Y25 - 1800X23 <= 0
  240Y15 + 408Y23 + 360Y24 + 292Y25 - 1800X24 <= 0
  408Y23 + 360Y24 + 292Y25 - 1800X25 <= 0
  272Y4 + 1000Y5 + 240Y6 + 272Y8 + 360Y24 - 1800X26 <= 0

3)X26 = 1
  X15 = 0

END
[Description of binary integer variables like INT X1]
```

APPENDIX C:

Mathematical Formulation for the P-Center Problem

```
MIN Z

SUBJECT TO
1) !If "ij" has three digits and starts with 1 or 2, X defines origin's name in first
two digits while K defines origin's name in the first digit.
X11 + X12 + X13 + X14 + X15 + X16 + X17 + X18 + X19 + X110 + K111 + K112 + K113 + K114
+ K115 + K116 + K117 + K118 + K119 + K120 + K121 + K122 + K123 + K124 + K125 + K126 =
1
X21 + X22 + X23 + X24 + X25 + X26 + X27 + X28 + X29 + X210 + K211 + K212 + K213 + K214
+ K215 + K216 + K217 + K218 + K219 + K220 + K221 + K222 + K223 + K224 + K225 + K226 =
1
X31 + X32 + X33 + X34 + X35 + X36 + X37 + X38 + X39 + X310 + X311 + X312 + X313 + X314
+ X315 + X316 + X317 + X318 + X319 + X320 + X321 + X322 + X323 + X324 + X325 + X326 =
1
X41 + X42 + X43 + X44 + X45 + X46 + X47 + X48 + X49 + X410 + X411 + X412 + X413 + X414
+ X415 + X416 + X417 + X418 + X419 + X420 + X421 + X422 + X423 + X424 + X425 + X426 =
1
X51 + X52 + X53 + X54 + X55 + X56 + X57 + X58 + X59 + X510 + X511 + X512 + X513 + X514
+ X515 + X516 + X517 + X518 + X519 + X520 + X521 + X522 + X523 + X524 + X525 + X526 =
1
X61 + X62 + X63 + X64 + X65 + X66 + X67 + X68 + X69 + X610 + X611 + X612 + X613 + X614
+ X615 + X616 + X617 + X618 + X619 + X620 + X621 + X622 + X623 + X624 + X625 + X626 =
1
X71 + X72 + X73 + X74 + X75 + X76 + X77 + X78 + X79 + X710 + X711 + X712 + X713 + X714
+ X715 + X716 + X717 + X718 + X719 + X720 + X721 + X722 + X723 + X724 + X725 + X726 =
1
X81 + X82 + X83 + X84 + X85 + X86 + X87 + X88 + X89 + X810 + X811 + X812 + X813 + X814
+ X815 + X816 + X817 + X818 + X819 + X820 + X821 + X822 + X823 + X824 + X825 + X826 =
1
X91 + X92 + X93 + X94 + X95 + X96 + X97 + X98 + X99 + X910 + X911 + X912 + X913 + X914
+ X915 + X916 + X917 + X918 + X919 + X920 + X921 + X922 + X923 + X924 + X925 + X926 =
1
X101 + X102 + X103 + X104 + X105 + X106 + X107 + X108 + X109 + X1010 + X1011 + X1012 +
X1013 + X1014 + X1015 + X1016 + X1017 + X1018 + X1019 + X1020 + X1021 + X1022 + X1023
+ X1024 + X1025+ X1026= 1
X111 + X112 + X113 + X114 + X115 + X116 + X117 + X118 + X119 + X1110 + X1111 + X1112 +
X1113 + X1114 + X1115 + X1116 + X1117 + X1118 + X1119 + X1120 + X1121 + X1122 + X1123
+ X1124 + X1125+ X1126= 1
X121 + X122 + X123 + X124 + X125 + X126 + X127 + X128 + X129 + X1210 + X1211 + X1212 +
X1213 + X1214 + X1215 + X1216 + X1217 + X1218 + X1219 + X1220 + X1221 + X1222 + X1223
+ X1224 + X1225+ X1226= 1
X131 + X132 + X133 + X134 + X135 + X136 + X137 + X138 + X139 + X1310 + X1311 + X1312 +
X1313 + X1314 + X1315 + X1316 + X1317 + X1318 + X1319 + X1320 + X1321 + X1322 + X1323
+ X1324 + X1325+ X1326= 1
X141 + X142 + X143 + X144 + X145 + X146 + X147 + X148 + X149 + X1410 + X1411 + X1412 +
X1413 + X1414 + X1415 + X1416 + X1417 + X1418 + X1419 + X1420 + X1421 + X1422 + X1423
+ X1424 + X1425+ X1426= 1
X151 + X152 + X153 + X154 + X155 + X156 + X157 + X158 + X159 + X1510 + X1511 + X1512 +
X1513 + X1514 + X1515 + X1516 + X1517 + X1518 + X1519 + X1520 + X1521 + X1522 + X1523
+ X1524 + X1525+ X1526= 1
X161 + X162 + X163 + X164 + X165 + X166 + X167 + X168 + X169 + X1610 + X1611 + X1612 +
X1613 + X1614 + X1615 + X1616 + X1617 + X1618 + X1619 + X1620 + X1621 + X1622 + X1623
+ X1624 + X1625+ X1626= 1
X171 + X172 + X173 + X174 + X175 + X176 + X177 + X178 + X179 + X1710 + X1711 + X1712 +
X1713 + X1714 + X1715 + X1716 + X1717 + X1718 + X1719 + X1720 + X1721 + X1722 + X1723
+ X1724 + X1725+ X1726= 1
```

```
X181 + X182 + X183 + X184 + X185 + X186 + X187 + X188 + X189 + X1810 + X1811 + X1812 +
X1813 + X1814 + X1815 + X1816 + X1817 + X1818 + X1819 + X1820 + X1821 + X1822 + X1823
+ X1824 + X1825+ X1826= 1
X191 + X192 + X193 + X194 + X195 + X196 + X197 + X198 + X199 + X1910 + X1911 + X1912 +
X1913 + X1914 + X1915 + X1916 + X1917 + X1918 + X1919 + X1920 + X1921 + X1922 + X1923
+ X1924 + X1925+ X1926= 1
X201 + X202 + X203 + X204 + X205 + X206 + X207 + X208 + X209 + X2010 + X2011 + X2012 +
X2013 + X2014 + X2015 + X2016 + X2017 + X2018 + X2019 + X2020 + X2021 + X2022 + X2023
+ X2024 + X2025+ X2026= 1
X211 + X212 + X213 + X214 + X215 + X216 + X217 + X218 + X219 + X2110 + X2111 + X2112 +
X2113 + X2114 + X2115 + X2116 + X2117 + X2118 + X2119 + X2120 + X2121 + X2122 + X2123
+ X2124 + X2125+ X2126= 1
X221 + X222 + X223 + X224 + X225 + X226 + X227 + X228 + X229 + X2210 + X2211 + X2212 +
X2213 + X2214 + X2215 + X2216 + X2217 + X2218 + X2219 + X2220 + X2221 + X2222 + X2223
+ X2224 + X2225+ X2226= 1
X231 + X232 + X233 + X234 + X235 + X236 + X237 + X238 + X239 + X2310 + X2311 + X2312 +
X2313 + X2314 + X2315 + X2316 + X2317 + X2318 + X2319 + X2320 + X2321 + X2322 + X2323
+ X2324 + X2325+ X2326= 1
X241 + X242 + X243 + X244 + X245 + X246 + X247 + X248 + X249 + X2410 + X2411 + X2412 +
X2413 + X2414 + X2415 + X2416 + X2417 + X2418 + X2419 + X2420 + X2421 + X2422 + X2423
+ X2424 + X2425+ X2426= 1
X251 + X252 + X253 + X254 + X255 + X256 + X257 + X258 + X259 + X2510 + X2511 + X2512 +
X2513 + X2514 + X2515 + X2516 + X2517 + X2518 + X2519 + X2520 + X2521 + X2522 + X2523
+ X2524 + X2525+ X2526= 1

2) ! Yj stands for Xj in the mathematical formulation.
X11 - Y1 <= 0
X12 - Y2 <= 0
X13 - Y3 <= 0
X14 - Y4 <= 0
X15 - Y5 <= 0
X16 - Y6 <= 0
X17 - Y7 <= 0
X18 - Y8 <= 0
X19 - Y9 <= 0
X110 - Y10 <= 0
K111 - Y11 <= 0
K112 - Y12 <= 0
K113 - Y13 <= 0
K114 - Y14 <= 0
K115 - Y15 <= 0
K116 - Y16 <= 0
K117 - Y17 <= 0
K118 - Y18 <= 0
K119 - Y19 <= 0
K120 - Y20 <= 0
K121 - Y21 <= 0
K122 - Y22 <= 0
K123 - Y23 <= 0
K124 - Y24 <= 0
K125 - Y25 <= 0
K126 - Y26 <= 0
X21 - Y1 <= 0
X22 - Y2 <= 0
X23 - Y3 <= 0
X24 - Y4 <= 0
X25 - Y5 <= 0
X26 - Y6 <= 0
X27 - Y7 <= 0
X28 - Y8 <= 0
X29 - Y9 <= 0
X210 - Y10 <= 0
K211 - Y11 <= 0
```

```
K212 - Y12 <= 0
K213 - Y13 <= 0
K214 - Y14 <= 0
K215 - Y15 <= 0
K216 - Y16 <= 0
K217 - Y17 <= 0
K218 - Y18 <= 0
K219 - Y19 <= 0
K220 - Y20 <= 0
K221 - Y21 <= 0
K222 - Y22 <= 0
K223 - Y23 <= 0
K224 - Y24 <= 0
K225 - Y25 <= 0
K226 - Y26 <= 0
X31 - Y1 <= 0
X32 - Y2 <= 0
X33 - Y3 <= 0
X34 - Y4 <= 0
X35 - Y5 <= 0
X36 - Y6 <= 0
X37 - Y7 <= 0
X38 - Y8 <= 0
X39 - Y9 <= 0
X310 - Y10 <= 0
X311 - Y11 <= 0
X312 - Y12 <= 0
X313 - Y13 <= 0
X314 - Y14 <= 0
X315 - Y15 <= 0
X316 - Y16 <= 0
X317 - Y17 <= 0
X318 - Y18 <= 0
X319 - Y19 <= 0
X320 - Y20 <= 0
X321 - Y21 <= 0
X322 - Y22 <= 0
X323 - Y23 <= 0
X324 - Y24 <= 0
X325 - Y25 <= 0
X326 - Y26 <= 0
X41 - Y1 <= 0
X42 - Y2 <= 0
X43 - Y3 <= 0
X44 - Y4 <= 0
X45 - Y5 <= 0
X46 - Y6 <= 0
X47 - Y7 <= 0
X48 - Y8 <= 0
X49 - Y9 <= 0
X410 - Y10 <= 0
X411 - Y11 <= 0
X412 - Y12 <= 0
X413 - Y13 <= 0
X414 - Y14 <= 0
X415 - Y15 <= 0
X416 - Y16 <= 0
X417 - Y17 <= 0
X418 - Y18 <= 0
X419 - Y19 <= 0
X420 - Y20 <= 0
X421 - Y21 <= 0
X422 - Y22 <= 0
```

```
X423 - Y23 <= 0
X424 - Y24 <= 0
X425 - Y25 <= 0
X426 - Y26 <= 0
X51 - Y1 <= 0
X52 - Y2 <= 0
X53 - Y3 <= 0
X54 - Y4 <= 0
X55 - Y5 <= 0
X56 - Y6 <= 0
X57 - Y7 <= 0
X58 - Y8 <= 0
X59 - Y9 <= 0
X510 - Y10 <= 0
X511 - Y11 <= 0
X512 - Y12 <= 0
X513 - Y13 <= 0
X514 - Y14 <= 0
X515 - Y15 <= 0
X516 - Y16 <= 0
X517 - Y17 <= 0
X518 - Y18 <= 0
X519 - Y19 <= 0
X520 - Y20 <= 0
X521 - Y21 <= 0
X522 - Y22 <= 0
X523 - Y23 <= 0
X524 - Y24 <= 0
X525 - Y25 <= 0
X526 - Y26 <= 0
X61 - Y1 <= 0
X62 - Y2 <= 0
X63 - Y3 <= 0
X64 - Y4 <= 0
X65 - Y5 <= 0
X66 - Y6 <= 0
X67 - Y7 <= 0
X68 - Y8 <= 0
X69 - Y9 <= 0
X610 - Y10 <= 0
X611 - Y11 <= 0
X612 - Y12 <= 0
X613 - Y13 <= 0
X614 - Y14 <= 0
X615 - Y15 <= 0
X616 - Y16 <= 0
X617 - Y17 <= 0
X618 - Y18 <= 0
X619 - Y19 <= 0
X620 - Y20 <= 0
X621 - Y21 <= 0
X622 - Y22 <= 0
X623 - Y23 <= 0
X624 - Y24 <= 0
X625 - Y25 <= 0
X626 - Y26 <= 06
X71 - Y1 <= 0
X72 - Y2 <= 0
X73 - Y3 <= 0
X74 - Y4 <= 0
X75 - Y5 <= 0
X76 - Y6 <= 0
X77 - Y7 <= 0
```

```
X78 - Y8 <= 0
X79 - Y9 <= 0
X710 - Y10 <= 0
X711 - Y11 <= 0
X712 - Y12 <= 0
X713 - Y13 <= 0
X714 - Y14 <= 0
X715 - Y15 <= 0
X716 - Y16 <= 0
X717 - Y17 <= 0
X718 - Y18 <= 0
X719 - Y19 <= 0
X720 - Y20 <= 0
X721 - Y21 <= 0
X722 - Y22 <= 0
X723 - Y23 <= 0
X724 - Y24 <= 0
X725 - Y25 <= 0
X726 - Y26 <= 0
X81 - Y1 <= 0
X82 - Y2 <= 0
X83 - Y3 <= 0
X84 - Y4 <= 0
X85 - Y5 <= 0
X86 - Y6 <= 0
X87 - Y7 <= 0
X88 - Y8 <= 0
X89 - Y9 <= 0
X810 - Y10 <= 0
X811 - Y11 <= 0
X812 - Y12 <= 0
X813 - Y13 <= 0
X814 - Y14 <= 0
X815 - Y15 <= 0
X816 - Y16 <= 0
X817 - Y17 <= 0
X818 - Y18 <= 0
X819 - Y19 <= 0
X820 - Y20 <= 0
X821 - Y21 <= 0
X822 - Y22 <= 0
X823 - Y23 <= 0
X824 - Y24 <= 0
X825 - Y25 <= 0
X826 - Y26 <= 0
X91 - Y1 <= 0
X92 - Y2 <= 0
X93 - Y3 <= 0
X94 - Y4 <= 0
X95 - Y5 <= 0
X96 - Y6 <= 0
X97 - Y7 <= 0
X98 - Y8 <= 0
X99 - Y9 <= 0
X910 - Y10 <= 0
X911 - Y11 <= 0
X912 - Y12 <= 0
X913 - Y13 <= 0
X914 - Y14 <= 0
X915 - Y15 <= 0
X916 - Y16 <= 0
X917 - Y17 <= 0
X918 - Y18 <= 0
```

```
X919 - Y19 <= 0
X920 - Y20 <= 0
X921 - Y21 <= 0
X922 - Y22 <= 0
X923 - Y23 <= 0
X924 - Y24 <= 0
X925 - Y25 <= 0
X926 - Y26 <= 0
X101 - Y1 <= 0
X102 - Y2 <= 0
X103 - Y3 <= 0
X104 - Y4 <= 0
X105 - Y5 <= 0
X106 - Y6 <= 0
X107 - Y7 <= 0
X108 - Y8 <= 0
X109 - Y9 <= 0
X1010 - Y10 <= 0
X1011 - Y11 <= 0
X1012 - Y12 <= 0
X1013 - Y13 <= 0
X1014 - Y14 <= 0
X1015 - Y15 <= 0
X1016 - Y16 <= 0
X1017 - Y17 <= 0
X1018 - Y18 <= 0
X1019 - Y19 <= 0
X1020 - Y20 <= 0
X1021 - Y21 <= 0
X1022 - Y22 <= 0
X1023 - Y23 <= 0
X1024 - Y24 <= 0
X1025 - Y25 <= 0
X1026 - Y26 <= 0
X111 - Y1 <= 0
X112 - Y2 <= 0
X113 - Y3 <= 0
X114 - Y4 <= 0
X115 - Y5 <= 0
X116 - Y6 <= 0
X117 - Y7 <= 0
X118 - Y8 <= 0
X119 - Y9 <= 0
X1110 - Y10 <= 0
X1111 - Y11 <= 0
X1112 - Y12 <= 0
X1113 - Y13 <= 0
X1114 - Y14 <= 0
X1115 - Y15 <= 0
X1116 - Y16 <= 0
X1117 - Y17 <= 0
X1118 - Y18 <= 0
X1119 - Y19 <= 0
X1120 - Y20 <= 0
X1121 - Y21 <= 0
X1122 - Y22 <= 0
X1123 - Y23 <= 0
X1124 - Y24 <= 0
X1125 - Y25 <= 0
X1126 - Y26 <= 0
X121 - Y1 <= 0
X122 - Y2 <= 0
X123 - Y3 <= 0
```

```
X124 - Y4 <= 0
X125 - Y5 <= 0
X126 - Y6 <= 0
X127 - Y7 <= 0
X128 - Y8 <= 0
X129 - Y9 <= 0
X1210 - Y10 <= 0
X1211 - Y11 <= 0
X1212 - Y12 <= 0
X1213 - Y13 <= 0
X1214 - Y14 <= 0
X1215 - Y15 <= 0
X1216 - Y16 <= 0
X1217 - Y17 <= 0
X1218 - Y18 <= 0
X1219 - Y19 <= 0
X1220 - Y20 <= 0
X1221 - Y21 <= 0
X1222 - Y22 <= 0
X1223 - Y23 <= 0
X1224 - Y24 <= 0
X1225 - Y25 <= 0
X1226 - Y26 <= 0
X131 - Y1 <= 0
X132 - Y2 <= 0
X133 - Y3 <= 0
X134 - Y4 <= 0
X135 - Y5 <= 0
X136 - Y6 <= 0
X137 - Y7 <= 0
X138 - Y8 <= 0
X139 - Y9 <= 0
X1310 - Y10 <= 0
X1311 - Y11 <= 0
X1312 - Y12 <= 0
X1313 - Y13 <= 0
X1314 - Y14 <= 0
X1315 - Y15 <= 0
X1316 - Y16 <= 0
X1317 - Y17 <= 0
X1318 - Y18 <= 0
X1319 - Y19 <= 0
X1320 - Y20 <= 0
X1321 - Y21 <= 0
X1322 - Y22 <= 0
X1323 - Y23 <= 0
X1324 - Y24 <= 0
X1325 - Y25 <= 0
X1326 - Y26 <= 0
X141 - Y1 <= 0
X142 - Y2 <= 0
X143 - Y3 <= 0
X144 - Y4 <= 0
X145 - Y5 <= 0
X146 - Y6 <= 0
X147 - Y7 <= 0
X148 - Y8 <= 0
X149 - Y9 <= 0
X1410 - Y10 <= 0
X1411 - Y11 <= 0
X1412 - Y12 <= 0
X1413 - Y13 <= 0
X1414 - Y14 <= 0
```

```
X1415 - Y15 <= 0
X1416 - Y16 <= 0
X1417 - Y17 <= 0
X1418 - Y18 <= 0
X1419 - Y19 <= 0
X1420 - Y20 <= 0
X1421 - Y21 <= 0
X1422 - Y22 <= 0
X1423 - Y23 <= 0
X1424 - Y24 <= 0
X1425 - Y25 <= 0
X1426 - Y26 <= 0
X151 - Y1 <= 0
X152 - Y2 <= 0
X153 - Y3 <= 0
X154 - Y4 <= 0
X155 - Y5 <= 0
X156 - Y6 <= 0
X157 - Y7 <= 0
X158 - Y8 <= 0
X159 - Y9 <= 0
X1510 - Y10 <= 0
X1511 - Y11 <= 0
X1512 - Y12 <= 0
X1513 - Y13 <= 0
X1514 - Y14 <= 0
X1515 - Y15 <= 0
X1516 - Y16 <= 0
X1517 - Y17 <= 0
X1518 - Y18 <= 0
X1519 - Y19 <= 0
X1520 - Y20 <= 0
X1521 - Y21 <= 0
X1522 - Y22 <= 0
X1523 - Y23 <= 0
X1524 - Y24 <= 0
X1525 - Y25 <= 0
X1526 - Y26 <= 0
X161 - Y1 <= 0
X162 - Y2 <= 0
X163 - Y3 <= 0
X164 - Y4 <= 0
X165 - Y5 <= 0
X166 - Y6 <= 0
X167 - Y7 <= 0
X168 - Y8 <= 0
X169 - Y9 <= 0
X1610 - Y10 <= 0
X1611 - Y11 <= 0
X1612 - Y12 <= 0
X1613 - Y13 <= 0
X1614 - Y14 <= 0
X1615 - Y15 <= 0
X1616 - Y16 <= 0
X1617 - Y17 <= 0
X1618 - Y18 <= 0
X1619 - Y19 <= 0
X1620 - Y20 <= 0
X1621 - Y21 <= 0
X1622 - Y22 <= 0
X1623 - Y23 <= 0
X1624 - Y24 <= 0
X1625 - Y25 <= 0
```

```
X1626 - Y26 <= 0
X171 - Y1 <= 0
X172 - Y2 <= 0
X173 - Y3 <= 0
X174 - Y4 <= 0
X175 - Y5 <= 0
X176 - Y6 <= 0
X177 - Y7 <= 0
X178 - Y8 <= 0
X179 - Y9 <= 0
X1710 - Y10 <= 0
X1711 - Y11 <= 0
X1712 - Y12 <= 0
X1713 - Y13 <= 0
X1714 - Y14 <= 0
X1715 - Y15 <= 0
X1716 - Y16 <= 0
X1717 - Y17 <= 0
X1718 - Y18 <= 0
X1719 - Y19 <= 0
X1720 - Y20 <= 0
X1721 - Y21 <= 0
X1722 - Y22 <= 0
X1723 - Y23 <= 0
X1724 - Y24 <= 0
X1725 - Y25 <= 0
X1726 - Y26 <= 0
X181 - Y1 <= 0
X182 - Y2 <= 0
X183 - Y3 <= 0
X184 - Y4 <= 0
X185 - Y5 <= 0
X186 - Y6 <= 0
X187 - Y7 <= 0
X188 - Y8 <= 0
X189 - Y9 <= 0
X1810 - Y10 <= 0
X1811 - Y11 <= 0
X1812 - Y12 <= 0
X1813 - Y13 <= 0
X1814 - Y14 <= 0
X1815 - Y15 <= 0
X1816 - Y16 <= 0
X1817 - Y17 <= 0
X1818 - Y18 <= 0
X1819 - Y19 <= 0
X1820 - Y20 <= 0
X1821 - Y21 <= 0
X1822 - Y22 <= 0
X1823 - Y23 <= 0
X1824 - Y24 <= 0
X1825 - Y25 <= 0
X1826 - Y26 <= 0
X191 - Y1 <= 0
X192 - Y2 <= 0
X193 - Y3 <= 0
X194 - Y4 <= 0
X195 - Y5 <= 0
X196 - Y6 <= 0
X197 - Y7 <= 0
X198 - Y8 <= 0
X199 - Y9 <= 0
X1910 - Y10 <= 0
```

```
X1911 - Y11 <= 0
X1912 - Y12 <= 0
X1913 - Y13 <= 0
X1914 - Y14 <= 0
X1915 - Y15 <= 0
X1916 - Y16 <= 0
X1917 - Y17 <= 0
X1918 - Y18 <= 0
X1919 - Y19 <= 0
X1920 - Y20 <= 0
X1921 - Y21 <= 0
X1922 - Y22 <= 0
X1923 - Y23 <= 0
X1924 - Y24 <= 0
X1925 - Y25 <= 0
X1926 - Y26 <= 0
X201 - Y1 <= 0
X202 - Y2 <= 0
X203 - Y3 <= 0
X204 - Y4 <= 0
X205 - Y5 <= 0
X206 - Y6 <= 0
X207 - Y7 <= 0
X208 - Y8 <= 0
X209 - Y9 <= 0
X2010 - Y10 <= 0
X2011 - Y11 <= 0
X2012 - Y12 <= 0
X2013 - Y13 <= 0
X2014 - Y14 <= 0
X2015 - Y15 <= 0
X2016 - Y16 <= 0
X2017 - Y17 <= 0
X2018 - Y18 <= 0
X2019 - Y19 <= 0
X2020 - Y20 <= 0
X2021 - Y21 <= 0
X2022 - Y22 <= 0
X2023 - Y23 <= 0
X2024 - Y24 <= 0
X2025 - Y25 <= 0
X2126 - Y26 <= 0
X211 - Y1 <= 0
X212 - Y2 <= 0
X213 - Y3 <= 0
X214 - Y4 <= 0
X215 - Y5 <= 0
X216 - Y6 <= 0
X217 - Y7 <= 0
X218 - Y8 <= 0
X219 - Y9 <= 0
X2110 - Y10 <= 0
X2111 - Y11 <= 0
X2112 - Y12 <= 0
X2113 - Y13 <= 0
X2114 - Y14 <= 0
X2115 - Y15 <= 0
X2116 - Y16 <= 0
X2117 - Y17 <= 0
X2118 - Y18 <= 0
X2119 - Y19 <= 0
X2120 - Y20 <= 0
X2121 - Y21 <= 0
```

```
X2122 - Y22 <= 0
X2123 - Y23 <= 0
X2124 - Y24 <= 0
X2125 - Y25 <= 0
X2126 - Y26 <= 0
X221 - Y1 <= 0
X222 - Y2 <= 0
X223 - Y3 <= 0
X224 - Y4 <= 0
X225 - Y5 <= 0
X226 - Y6 <= 0
X227 - Y7 <= 0
X228 - Y8 <= 0
X229 - Y9 <= 0
X2210 - Y10 <= 0
X2211 - Y11 <= 0
X2212 - Y12 <= 0
X2213 - Y13 <= 0
X2214 - Y14 <= 0
X2215 - Y15 <= 0
X2216 - Y16 <= 0
X2217 - Y17 <= 0
X2218 - Y18 <= 0
X2219 - Y19 <= 0
X2220 - Y20 <= 0
X2221 - Y21 <= 0
X2222 - Y22 <= 0
X2223 - Y23 <= 0
X2224 - Y24 <= 0
X2225 - Y25 <= 0
X2226 - Y26 <= 0
X231 - Y1 <= 0
X232 - Y2 <= 0
X233 - Y3 <= 0
X234 - Y4 <= 0
X235 - Y5 <= 0
X236 - Y6 <= 0
X237 - Y7 <= 0
X238 - Y8 <= 0
X239 - Y9 <= 0
X2310 - Y10 <= 0
X2311 - Y11 <= 0
X2312 - Y12 <= 0
X2313 - Y13 <= 0
X2314 - Y14 <= 0
X2315 - Y15 <= 0
X2316 - Y16 <= 0
X2317 - Y17 <= 0
X2318 - Y18 <= 0
X2319 - Y19 <= 0
X2320 - Y20 <= 0
X2321 - Y21 <= 0
X2322 - Y22 <= 0
X2323 - Y23 <= 0
X2324 - Y24 <= 0
X2325 - Y25 <= 0
X2326 - Y26 <= 0
X241 - Y1 <= 0
X242 - Y2 <= 0
X243 - Y3 <= 0
X244 - Y4 <= 0
X245 - Y5 <= 0
X246 - Y6 <= 0
```

```
X247 - Y7 <= 0
X248 - Y8 <= 0
X249 - Y9 <= 0
X2410 - Y10 <= 0
X2411 - Y11 <= 0
X2412 - Y12 <= 0
X2413 - Y13 <= 0
X2414 - Y14 <= 0
X2415 - Y15 <= 0
X2416 - Y16 <= 0
X2417 - Y17 <= 0
X2418 - Y18 <= 0
X2419 - Y19 <= 0
X2420 - Y20 <= 0
X2421 - Y21 <= 0
X2422 - Y22 <= 0
X2423 - Y23 <= 0
X2424 - Y24 <= 0
X2425 - Y25 <= 0
X2426 - Y26 <= 0
X251 - Y1 <= 0
X252 - Y2 <= 0
X253 - Y3 <= 0
X254 - Y4 <= 0
X255 - Y5 <= 0
X256 - Y6 <= 0
X257 - Y7 <= 0
X258 - Y8 <= 0
X259 - Y9 <= 0
X2510 - Y10 <= 0
X2511 - Y11 <= 0
X2512 - Y12 <= 0
X2513 - Y13 <= 0
X2514 - Y14 <= 0
X2515 - Y15 <= 0
X2516 - Y16 <= 0
X2517 - Y17 <= 0
X2518 - Y18 <= 0
X2519 - Y19 <= 0
X2520 - Y20 <= 0
X2521 - Y21 <= 0
X2522 - Y22 <= 0
X2523 - Y23 <= 0
X2524 - Y24 <= 0
X2525 - Y25 <= 0
X2526 - Y26 <= 0

3) 0 X11 + 5.3 X12 + 27.2 X13 + 16.7 X14 + 11.4 X15 + 14.2 X16 + 12.4 X17 + 14.6 X18 +
17.6 X19 + 27.8 X110 + 12.2 K111 + 17.3 K112 + 15.4 K113 + 14.7 K114 + 48.6 K115 +
31.3 K116 + 22.3 K117 + 36.6 K118 + 26.2 K119 + 33.3 K120 + 39.9 K121 + 43 K122 + 56.6
K123 + 43.7 K124 + 50.4 K125 + 25.7 K126 - Z <= 0
5.3 X21 + 0 X22 + 28.4 X23 + 18 X24 + 12.7 X25 + 10.9 X26 + 9.2 X27 + 15.9 X28 + 18.9
X29 + 33 X210 + 17.5 K211 + 22.6 K212 + 20.6 K213 + 20 K214 + 53.9 K215 + 32.6 K216 +
25.6 K217 + 37.8 K218 + 27.5 K219 + 34.6 K220 + 41.2 K221 + 44.3 K222 + 57.9 K223 + 45
K224 + 51.7 K225 + 27 K226 - Z <= 0
27.2 X31 + 28.4 X32 + 0 X33 + 12 X34 + 16.2 X35 + 36 X36 + 35.7 X37 + 15.7 X38 + 22.4
X39 + 54.9 X310 + 39.4 X311 + 44.5 X312 + 42.5 X313 + 41.9 X314 + 58.8 X315 + 36.1
X316 + 27 X317 + 41.3 X318 + 31 X319 + 38.1 X320 + 44.6 X321 + 47.8 X322 + 52.3 X323 +
39.5 X324 + 46.1 X325 + 21.5 X326 - Z <= 0
16.7 X41 + 18 X42 + 12 X43 + 0 X44 + 5.8 X45 + 25.5 X46 + 25.2 X47 + 5.3 X48 + 11.9
X49 + 44.5 X410 + 28.9 X411 + 34 X412 + 32.1 X413 + 31.5 X414 + 48.4 X415 + 25.6 X416
+ 16.6 X417 + 30.9 X418 + 20.5 X419 + 27.6 X420 + 34.2 X421 + 37.4 X422 + 41.9 X423 +
29 X424 + 35.7 X425 + 11.1 X426 - Z <= 0
```

11.4 X51 + 12.7 X52 + 16.2 X53 + 5.8 X54 + 0 X55 + 21.6 X56 + 19.9 X57 + 3.6 X58 + 6.2 X59 + 28.9 X510 + 23.6 X511 + 28.7 X512 + 26.8 X513 + 26.1 X514 + 52.1 X515 + 19.9 X516 + 10.8 X517 + 25.1 X518 + 14.8 X519 + 21.9 X520 + 28.5 X521 + 21.6 X522 + 45.6 X523 + 32.7 X524 + 39.4 X525 + 14.8 X526 - Z <= 0

14.2 X61 + 10.9 X62 + 36 X63 + 25.5X64 + 21.6 X65 + 0 X66 + 7.8 X67 + 24.7 X68 + 27.8 X69 + 41.9 X610 + 26.4 X611 + 31.5 X612 + 29.5 X613 + 28.9 X614 + 50.5 X615 + 41.5 X616 + 32.5 X617 + 46.7 X618 + 36.4 X619 + 43.5 X620 + 50 X621 + 53.2 X622 + 44 X623 + 31.1 X624 + 37.8 X625 + 14.4 X626 - Z <= 0

12.4 X71 + 9.2 X72 + 35.6 X73 + 25.2 X74 + 19.9 X75 + 7.8 X76 + 0 X77 + 23 X78 + 26 X79 + 40.2 X710 + 24.6 X711 + 29.7 X712 + 27.8 X713 + 27.1 X714 + 58.3 X715 + 39.7 X716 + 30.7 X717 + 45 X718 + 34.6 X719 + 41.7 X720 + 48.3 X721 + 51.5 X722 + 51.8 X723 + 39 X724 + 45.7 X725 + 22.3 X726 - Z <= 0

14.6 X81 + 15.9 X82 + 15.7 X83 + 5.3 X84 + 3.6 X85 + 24.7 X86 + 23 X87 + 0 X88 + 9.8 X89 + 42.4 X810 + 26.8 X811 + 31.9 X812 + 29.9 X813 + 29.3 X814 + 51.6 X815 + 23.5 X816 + 14.4 X817 + 28.7 X818 + 18.4 X819 + 25.5 X820 + 32.1 X821 + 35.2 X822 + 45.1 X823 + 32.2 X824 + 38.9 X825 + 14.3 X826 - Z <= 0

17.6 X91 + 18.9 X92 + 22.4 X93 + 11.9 X94 + 6.2 X95 + 27.8 X96 + 26 X97 + 9.8 X98 + 0 X99 + 45.4 X910 + 29.8X911 + 34.9X912 + 33 X913 + 32.3 X914 + 58.3 X915 + 19.6 X916 + 10.6 X917 + 26.9 X918 + 19.6 X919 + 26.8 X920 + 28.2 X921 + 31.3 X922 + 51.8 X923 + 38.9 X924 + 45.6 X925 + 20.9 X926 - Z <= 0

27.8 X101 + 33 X102 + 54.9 X103 + 44.5 X104 + 39.2 X105 + 41.9 X106 + 40.2 X107 + 42.4 X108 + 45.4 X109 + 0 X1010 + 15.6 X1011 + 20.7 X1012 + 12.4 X1013 + 18.1 X1014 + 21.1 X1015 + 59 X1016 + 50 X1017 + 64.3 X1018 + 54 X1019 + 61.1 X1020 + 67.7 X1021 + 70.8 X1022 + 39.1 X1023 + 26.2 X1024 + 32.9 X1025 + 39.7 X1026 - Z <= 0

12.2 X111 + 17.5 X112 + 39.4 X113 + 28.9 X114 + 23.6 X115 + 26.4 X116 + 24.6 X117 + 26.8 X118 + 29.8 X119 + 15.6 X1110 + 0 X1111 + 5.2 X1112 + 3.1 X1113 + 2.6 X1114 + 36.3 X1115 + 43.5 X1116 + 34.6 X1117 + 48.9 X1118 + 38.5 X1119 + 45.6 X1120 + 52.2 X1121 + 55.3 X1122 + 54.3 X1123 + 41.4 X1124 + 48.1 X1125 + 38 X1126 - Z <= 0

17.3 X121 + 22.6 X122 + 44.5 X123 + 34 X124 + 28.7 X125 + 31.5 X126 + 29.7 X127 + 31.9 X128 + 34.9 X129 + 20.7 X1210 + 5.2 X1211 + 0 X1212 + 8.2 X1213 + 6.3 X1214 + 41.5 X1215 + 48.6 X1216 + 39.6 X1217 + 53.9 X1218 + 43.5 X1219 + 50.6 X1220 + 57.2 X1221 + 60.3 X1222 + 59.5 X1223 + 46.6 X1224 + 53.3 X1225 + 43 X1226 - Z <= 0

15.4 X131 + 20.6 X132 + 42.5 X133 + 32.1 X134 + 26.8 X135 + 29.5 X136 + 27.8 X137 + 29.9 X138 + 33 X139 + 12.4 X1310 + 3.1 X1311 + 8.2 X1312 + 0 X1313 + 5.7 X1314 + 33.3 X1315 + 46.6 X1316 + 37.6 X1317 + 51.9 X1318 + 41.6 X1319 + 48.7 X1320 + 55.2 X1321 + 58.4 X1322 + 51.2 X1323 + 38.3 X1324 + 45 X1325 + 41.1 X1326 - Z <= 0

14.7 X141 + 20 X142 + 41.9 X143 + 31.5 X144 + 26.1 X145 + 28.9 X146 + 27.1 X147 + 29.3 X148 + 32.3 X149 + 18.1 X1410 + 2.6 X1411 + 6.3 X1412 + 5.7 X1413 + 0 X1414 + 38.9 X1415 + 46 X1416 + 37 X1417 + 51.3 X1418 + 40.9 X1419 + 48 X1420 + 54.6 X1421 + 57.7 X1422 + 56.9 X1423 + 44 X1424 + 50.7 X1425 + 40.5 X1426 - Z <= 0

48.6 X151 + 53.9 X152 + 58.8 X153 + 48.4 X154 + 52.1 X155 + 50.5 X156 + 58.3 X157 + 51.6 X158 + 58.3 X159 + 21.1 X1510 + 36.3 X1511 + 41.5 X1512 + 33.3 X1513 + 38.9 X1514 + 0 X1515 + 71.9 X1516 + 63 X1517 + 77.2 X1518 + 66.9 X1519 + 74 X1520 + 80.6 X1521 + 83.7 X1522 + 36.7 X1523 + 23.8 X1524 + 30.5 X1525 + 37.3 X1526 - Z <= 0

31.3 X161 + 32.6 X162 + 36.1 X163 + 25.6 X164 + 19.9 X165 + 41.5 X166 + 39.7 X167 + 23.5 X168 + 19.6 X169 + 59 X1610 + 43.5 X1611 + 48.6 X1612 + 46.6 X1613 + 46 X1614 + 71.9 X1615 + 0 X1616 + 9 X1617 + 7.4 X1618 + 17.7 X1619 + 10.6 X1620 + 8.6 X1621 + 11.8 X1622 + 65.4 X1623 + 52.6 X1624 + 59.2 X1625 + 34.6 X1626 - Z <= 0

22.3 X171 + 25.6 X172 + 27 X173 + 16.6 X174 + 10.8 X175 + 32.5 X176 + 30.7 X177 + 14.4 X178 + 10.6 X179 + 50 X1710 + 34.6 X1711 + 39.6 X1712 + 37.6 X1713 + 37 X1714 + 63 X1715 + 9 X1716 + 0 X1717 + 65.9 X1718 + 55.6 X1719 + 62.7 X1720 + 69.2 X1721 + 72.4 X1722 + 85.9 X1723 + 73.1 X1724 + 79.8 X1725 + 25.6 X1726 - Z <= 0

36.6 X181 + 37.8 X182 + 41.3 X183 + 30.9 X184 + 25.1 X185 + 46.7 X186 + 45 X187 + 28.7 X188 + 26.9 X189 + 64.3 X1810 + 48.9 X1811 + 53.9 X1812 + 51.9 X1813 + 51.3 X1814 + 77.2 X1815 + 7.4 X1816 + 65.9 X1817 + 0 X1818 + 10.3 X1819 + 3.2 X1820 + 15.9 X1821 + 19 X1822 + 70.7 X1823 + 57.9 X1824 + 64.6 X1825 + 39.9 X1826 - Z <= 0

26.2 X191 + 27.5 X192 + 31 X193 + 20.5 X194 + 14.8 X195 + 36.4 X196 + 34.6 X197 + 18.4 X198 + 19.6 X199 + 54 X1910 + 38.5 X1911 + 43.5 X1912 + 41.6 X1913 + 40.9 X1914 + 66.9 X1915 + 17.7 X1916 + 55.6 X1917 + 10.3 X1918 + 0 X1919 + 7.1 X1920 + 26.2 X1921 + 29.4 X1922 + 60.4 X1923 + 47.5 X1924 + 54.2 X1925 + 29.5 X1926 - Z <= 0

33.3 X201 + 34.6 X202 + 38.1 X203 + 27.6 X204 + 21.9 X205 + 43.5 X206 + 41.7 X207 + 25.5 X208 + 26.8 X209 + 61.1 X2010 + 45.6 X2011 + 50.6 X2012 + 48.7 X2013 + 48 X2014 +

74 X2015 + 10.6 X2016 + 62.7 X2017 + 3.2 X2018 + 7.1 X2019 + 0 X2020 + 19.1 X2021 +
22.3 X2022 + 67.5 X2023 + 54.6 X2024 + 61.3 X2025 + 36.7 X2026 - Z <= 0
39.9 X211 + 41.2 X212 + 44.6 X213 + 34.2 X214 + 28.5 X215 + 50 X216 + 48.3 X217 + 32.1
X218 + 28.2 X219 + 67.7 X2110 + 52.2 X2111 + 57.2 X2112 + 55.2 X2113 + 54.6 X2114 +
80.6 X2115 + 8.6 X2116 + 69.2 X2117 + 15.9 X2118 + 26.2 X2119 + 19.1 X2120 + 0 X2121 +
14.9 X2122 + 74 X2123 + 61.2 X2124 + 67.9 X2125 + 43.2 X2126 - Z <= 0
43 X221 + 44.3 X222 + 47.8 X223 + 37.4 X224 + 31.6 X225 + 53.2 X226 + 51.5 X227 + 35.2
X228 + 31.3 X229 + 70.8 X2210 + 55.3 X2211 + 60.3 X2212 + 58.4 X2213 + 57.7 X2214 +
83.7 X2215 + 11.8 X2216 + 72.4 X2217 + 19 X2218 + 29.4 X2219 + 22.3 X2220 + 14.9 X2221
+ 0 X2222 + 77.2 X2223 + 64.3 X2224 + 71 X2225 + 46.4 X2226 - Z <= 0
56.6 X231 + 57.9 X232 + 52.3 X233 + 41.9 X234 + 45.6 X235 + 44 X236 + 51.8 X237 + 45.1
X238 + 51.8 X239 + 39.1 X2310 + 54.3 X2311 + 59.5 X2312 + 51.2 X2313 + 56.9 X2314 +
36.7 X2315 + 65.4 X2316 + 85.9 X2317 + 70.7 X2318 + 60.4 X2319 + 67.5 X2320 + 74 X2321
+ 77.2 X2322 + 0 X2323 + 12.9 X2324 + 11.1 X2325 + 30.8 X2326 - Z <= 0
43.7 X241 + 45 X242 + 39.5 X243 + 29 X244 + 32.7 X245 + 31.1 X246 + 39 X247 + 32.2
X248 + 38.9 X249 + 26.2 X2410 + 41.4 X2411 + 46.6 X2412 + 38.3 X2413 + 44 X2414 + 23.8
X2415 + 52.6 X2416 + 73.1 X2417 + 57.9 X2418 + 47.5 X2419 + 54.6 X2420 + 61.2 X2421 +
64.3 X2422 + 12.9 X2423 + 0 X2424 + 6.7 X2425 + 18 X2426 - Z <= 0
50.2 X251 + 51.7 X252 + 46.1 X253 + 35.7 X254 + 39.4 X255 + 37.8 X256 + 45.7 X257 +
38.9 X258 + 45.6 X259 + 32.9 X2510 + 48.1 X2511 + 53.3 X2512 + 45 X2513 + 50.7 X2514 +
30.5 X2515 + 59.2 X2516 + 79.8 X2517 + 64.6 X2518 + 54.2 X2519 + 61.3 X2520 + 67.9
X2521 + 71 X2522 + 11.1 X2523 + 6.7 X2524 + 0 X2525 + 24.7 X2526 - Z <= 0

4) Y1 + Y2 + Y3 + Y4 + Y5 + Y6 + Y7 + Y8 + Y9 + Y10 + Y11 + Y12 + Y13 + Y14 + Y15 +
Y16 + Y17 + Y18 + Y19 + Y20 + Y21 + Y22+ Y23 + Y24 + Y25 + Y26 <= 5

5) Y1 = 0
Y2 = 0
Y3 = 0
Y4 = 0
Y7 = 0
Y8 = 0
Y12 = 0
Y14 = 0
Y15 = 0
Y17 = 0
Y18 = 0
Y19 = 0
Y20 = 0
Y22 = 0
Y23 = 0
Y24 = 0
Y25 = 0

END
[definition of binary integer variables like INT Y1]

APPENDIX D:

Mathematical Formulation for the P-Median Problem

```
MIN 0 X11 + 5.3 X12 + 27.2 X13 + 16.7 X14 + 11.4 X15 + 14.2 X16 + 12.4 X17 + 14.6 X18
+ 17.6 X19 + 27.8 X110 + 12.2 K111 + 17.3 K112 + 15.4 K113 + 14.7 K114 + 48.6 K115 +
31.3 K116 + 22.3 K117 + 36.6 K118 + 26.2 K119 + 33.3 K120 + 39.9 K121 + 43 K122 + 56.6
K123 + 43.7 K124 + 50.4 K125 + 25.7 K126 + 5.3 X21 + 0 X22 + 28.4 X23 + 18 X24 + 12.7
X25 + 10.9 X26 + 9.2 X27 + 15.9 X28 + 18.9 X29 + 33 X210 + 17.5 K211 + 22.6 K212 +
20.6 K213 + 20 K214 + 53.9 K215 + 32.6 K216 + 25.6 K217 + 37.8 K218 + 27.5 K219 + 34.6
K220 + 41.2 K221 + 44.3 K222 + 57.9 K223 + 45 K224 + 51.7 K225 + 27 K226 + 27.2 X31 +
28.4 X32 + 0 X33 + 12 X34 + 16.2 X35 + 36 X36 + 35.7 X37 + 15.7 X38 + 22.4 X39 + 54.9
X310 + 39.4 X311 + 44.5 X312 + 42.5 X313 + 41.9 X314 + 58.8 X315 + 36.1 X316 + 27 X317
+ 41.3 X318 + 31 X319 + 38.1 X320 + 44.6 X321 + 47.8 X322 + 52.3 X323 + 39.5 X324 +
46.1 X325 + 21.5 X326 + 16.7 X41 + 18 X42 + 12 X43 + 0 X44 + 5.8 X45 + 25.5 X46 + 25.2
X47 + 5.3 X48 + 11.9 X49 + 44.5 X410 + 28.9 X411 + 34 X412 + 32.1 X413 + 31.5 X414 +
48.4 X415 + 25.6 X416 + 16.6 X417 + 30.9 X418 + 20.5 X419 + 27.6 X420 + 34.2 X421 +
37.4 X422 + 41.9 X423 + 29 X424 + 35.7 X425 + 11.1 X426 + 11.4 X51 + 12.7 X52 + 16.2
X53 + 5.8 X54 + 0 X55 + 21.6 X56 + 19.9 X57 + 3.6 X58 + 6.2 X59 + 28.9 X510 + 23.6
X511 + 28.7 X512 + 26.8 X513 + 26.1 X514 + 52.1 X515 + 19.9 X516 + 10.8 X517 + 25.1
X518 + 14.8 X519 + 21.9 X520 + 28.5 X521 + 21.6 X522 + 45.6 X523 + 32.7 X524 + 39.4
X525 + 14.8 X526 + 14.2 X61 + 10.9 X62 + 36 X63 + 25.5X64 + 21.6 X65 + 0 X66 + 7.8 X67
+ 24.7 X68 + 27.8 X69 + 41.9 X610 + 26.4 X611 + 31.5 X612 + 29.5 X613 + 28.9 X614 +
50.5 X615 + 41.5 X616 + 32.5 X617 + 46.7 X618 + 36.4 X619 + 43.5 X620 + 50 X621 + 53.2
X622 + 44 X623 + 31.1 X624 + 37.8 X625 + 14.4 X626 + 12.4 X71 + 9.2 X72 + 35.6 X73 +
25.2 X74 + 19.9 X75 + 7.8 X76 + 0 X77 + 23 X78 + 26 X79 + 40.2 X710 + 24.6 X711 + 29.7
X712 + 27.8 X713 + 27.1 X714 + 58.3 X715 + 39.7 X716 + 30.7 X717 + 45 X718 + 34.6 X719
+ 41.7 X720 + 48.3 X721 + 51.5 X722 + 51.8 X723 + 39 X724 + 45.7 X725 + 22.3 X726 +
14.6 X81 + 15.9 X82 + 15.7 X83 + 5.3 X84 + 3.6 X85 + 24.7 X86 + 23 X87 + 0 X88 + 9.8
X89 + 42.4 X810 + 26.8 X811 + 31.9 X812 + 29.9 X813 + 29.3 X814 + 51.6 X815 + 23.5
X816 + 14.4 X817 + 28.7 X818 + 18.4 X819 + 25.5 X820 + 32.1 X821 + 35.2 X822 + 45.1
X823 + 32.2 X824 + 38.9 X825 + 14.3 X826 + 17.6 X91 + 18.9 X92 + 22.4 X93 + 11.9 X94 +
6.2 X95 + 27.8 X96 + 26 X97 + 9.8 X98 + 0 X99 + 45.4 X910 + 29.8X911 + 34.9 X912 + 33
X913 + 32.3 X914 + 58.3 X915 + 19.6 X916 + 10.6 X917 + 26.9 X918 + 19.6 X919 + 26.8
X920 + 28.2 X921 + 31.3 X922 + 51.8 X923 + 38.9 X924 + 45.6 X925 + 20.9 X926 + 27.8
X101 + 33 X102 + 54.9 X103 + 44.5 X104 + 39.2 X105 + 41.9 X106 + 40.2 X107 + 42.4 X108
+ 45.4 X109 + 0 X1010 + 15.6 X1011 + 20.7 X1012 + 12.4 X1013 + 18.1 X1014 + 21.1 X1015
+ 59 X1016 + 50 X1017 + 64.3 X1018 + 54 X1019 + 61.1 X1020 + 67.7 X1021 + 70.8 X1022 +
39.1 X1023 + 26.2 X1024 + 32.9 X1025 + 39.7 X1026 + 12.2 X111 + 17.5 X112 + 39.4 X113
+ 28.9 X114 + 23.6 X115 + 26.4 X116 + 24.6 X117 + 26.8 X118 + 29.8 X119 + 15.6 X1110 +
0 X1111 + 5.2 X1112 + 3.1 X1113 + 2.6 X1114 + 36.3 X1115 + 43.5 X1116 + 34.6 X1117 +
48.9 X1118 + 38.5 X1119 + 45.6 X1120 + 52.2 X1121 + 55.3 X1122 + 54.3 X1123 + 41.4
X1124 + 48.1 X1125 + 38 X1126 + 17.3 X121 + 22.6 X122 + 44.5 X123 + 34 X124 + 28.7
X125 + 31.5 X126 + 29.7 X127 + 31.9 X128 + 34.9 X129 + 20.7 X1210 + 5.2 X1211 + 0
X1212 + 8.2 X1213 + 6.3 X1214 + 41.5 X1215 + 48.6 X1216 + 39.6 X1217 + 53.9 X1218 +
43.5 X1219 + 50.6 X1220 + 57.2 X1221 + 60.3 X1222 + 59.5 X1223 + 46.6 X1224 + 53.3
X1225 + 43 X1226 + 15.4 X131 + 20.6 X132 + 42.5 X133 + 32.1 X134 + 26.8 X135 + 29.5
X136 + 27.8 X137 + 29.9 X138 + 33 X139 + 12.4 X1310 + 3.1 X1311 + 8.2 X1312 + 0 X1313
+ 5.7 X1314 + 33.3 X1315 + 46.6 X1316 + 37.6 X1317 + 51.9 X1318 + 41.6 X1319 + 48.7
X1320 + 55.2 X1321 + 58.4 X1322 + 51.2 X1323 + 38.3 X1324 + 45 X1325 + 41.1 X1326 +
14.7 X141 + 20 X142 + 41.9 X143 + 31.5 X144 + 26.1 X145 + 28.9 X146 + 27.1 X147 + 29.3
X148 + 32.3 X149 + 18.1 X1410 + 2.6 X1411 + 6.3 X1412 + 5.7 X1413 + 0 X1414 + 38.9
X1415 + 46 X1416 + 37 X1417 + 51.3 X1418 + 40.9 X1419 + 48 X1420 + 54.6 X1421 + 57.7
X1422 + 56.9 X1423 + 44 X1424 + 50.7 X1425 + 40.5 X1426 + 48.6 X151 + 53.9 X152 + 58.8
X153 + 48.4 X154 + 52.1 X155 + 50.5 X156 + 58.3 X157 + 51.6 X158 + 58.3 X159 + 21.1
X1510 + 36.3 X1511 + 41.5 X1512 + 33.3 X1513 + 38.9 X1514 + 0 X1515 + 71.9 X1516 + 63
X1517 + 77.2 X1518 + 66.9 X1519 + 74 X1520 + 80.6 X1521 + 83.7 X1522 + 36.7 X1523 +
23.8 X1524 + 30.5 X1525 + 37.3 X1526 + 31.3 X161 + 32.6 X162 + 36.1 X163 + 25.6 X164 +
19.9 X165 + 41.5 X166 + 39.7 X167 + 23.5 X168 + 19.6 X169 + 59 X1610 + 43.5 X1611 +
48.6 X1612 + 46.6 X1613 + 46 X1614 + 71.9 X1615 + 0 X1616 + 9 X1617 + 7.4 X1618 + 17.7
```

X1619 + 10.6 X1620 + 8.6 X1621 + 11.8 X1622 + 65.4 X1623 + 52.6 X1624 + 59.2 X1625 + 34.6 X1626 + 22.3 X171 + 25.6 X172 + 27 X173 + 16.6 X174 + 10.8 X175 + 32.5 X176 + 30.7 X177 + 14.4 X178 + 10.6 X179 + 50 X1710 + 34.6 X1711 + 39.6 X1712 + 37.6 X1713 + 37 X1714 + 63 X1715 + 9 X1716 + 0 X1717 + 65.9 X1718 + 55.6 X1719 + 62.7 X1720 + 69.2 X1721 + 72.4 X1722 + 85.9 X1723 + 73.1 X1724 + 79.8 X1725 + 25.6 X1726 + 36.6 X181 + 37.8 X182 + 41.3 X183 + 30.9 X184 + 25.1 X185 + 46.7 X186 + 45 X187 + 28.7 X188 + 26.9 X189 + 64.3 X1810 + 48.9 X1811 + 53.9 X1812 + 51.9 X1813 + 51.3 X1814 + 77.2 X1815 + 7.4 X1816 + 65.9 X1817 + 0 X1818 + 10.3 X1819 + 3.2 X1820 + 15.9 X1821 + 19 X1822 + 70.7 X1823 + 57.9 X1824 + 64.6 X1825 + 39.9 X1826 + 26.2 X191 + 27.5 X192 + 31 X193 + 20.5 X194 + 14.8 X195 + 36.4 X196 + 34.6 X197 + 18.4 X198 + 19.6 X199 + 54 X1910 + 38.5 X1911 + 43.5 X1912 + 41.6 X1913 + 40.9 X1914 + 66.9 X1915 + 17.7 X1916 + 55.6 X1917 + 10.3 X1918 + 0 X1919 + 7.1 X1920 + 26.2 X1921 + 29.4 X1922 + 60.4 X1923 + 47.5 X1924 + 54.2 X1925 + 29.5 X1926 + 33.3 X201 + 34.6 X202 + 38.1 X203 + 27.6 X204 + 21.9 X205 + 43.5 X206 + 41.7 X207 + 25.5 X208 + 26.8 X209 + 61.1 X2010 + 45.6 X2011 + 50.6 X2012 + 48.7 X2013 + 48 X2014 + 74 X2015 + 10.6 X2016 + 62.7 X2017 + 3.2 X2018 + 7.1 X2019 + 0 X2020 + 19.1 X2021 + 22.3 X2022 + 67.5 X2023 + 54.6 X2024 + 61.3 X2025 + 36.7 X2026 + 39.9 X211 + 41.2 X212 + 44.6 X213 + 34.2 X214 + 28.5 X215 + 50 X216 + 48.3 X217 + 32.1 X218 + 28.2 X219 + 67.7 X2110 + 52.2 X2111 + 57.2 X2112 + 55.2 X2113 + 54.6 X2114 + 80.6 X2115 + 8.6 X2116 + 69.2 X2117 + 15.9 X2118 + 26.2 X2119 + 19.1 X2120 + 0 X2121 + 14.9 X2122 + 74 X2123 + 61.2 X2124 + 67.9 X2125 + 43.2 X2126 + 43 X221 + 44.3 X222 + 47.8 X223 + 37.4 X224 + 31.6 X225 + 53.2 X226 + 51.5 X227 + 35.2 X228 + 31.3 X229 + 70.8 X2210 + 55.3 X2211 + 60.3 X2212 + 58.4 X2213 + 57.7 X2214 + 83.7 X2215 + 11.8 X2216 + 72.4 X2217 + 19 X2218 + 29.4 X2219 + 22.3 X2220 + 14.9 X2221 + 0 X2222 + 77.2 X2223 + 64.3 X2224 + 71 X2225 + 46.4 X2226 + 56.6 X231 + 57.9 X232 + 52.3 X233 + 41.9 X234 + 45.6 X235 + 44 X236 + 51.8 X237 + 45.1 X238 + 51.8 X239 + 39.1 X2310 + 54.3 X2311 + 59.5 X2312 + 51.2 X2313 + 56.9 X2314 + 36.7 X2315 + 65.4 X2316 + 85.9 X2317 + 70.7 X2318 + 60.4 X2319 + 67.5 X2320 + 74 X2321 + 77.2 X2322 + 0 X2323 + 12.9 X2324 + 11.1 X2325 + 30.8 X2326 + 43.7 X241 + 45 X242 + 39.5 X243 + 29 X244 + 32.7 X245 + 31.1 X246 + 39 X247 + 32.2 X248 + 38.9 X249 + 26.2 X2410 + 41.4 X2411 + 46.6 X2412 + 38.3 X2413 + 44 X2414 + 23.8 X2415 + 52.6 X2416 + 73.1 X2417 + 57.9 X2418 + 47.5 X2419 + 54.6 X2420 + 61.2 X2421 + 64.3 X2422 + 12.9 X2423 + 0 X2424 + 6.7 X2425 + 18 X2426 + 50.2 X251 + 51.7 X252 + 46.1 X253 + 35.7 X254 + 39.4 X255 + 37.8 X256 + 45.7 X257 + 38.9 X258 + 45.6 X259 + 32.9 X2510 + 48.1 X2511 + 53.3 X2512 + 45 X2513 + 50.7 X2514 + 30.5 X2515 + 59.2 X2516 + 79.8 X2517 + 64.6 X2518 + 54.2 X2519 + 61.3 X2520 + 67.9 X2521 + 71 X2522 + 11.1 X2523 + 6.7 X2524 + 0 X2525 + 24.7 X2526

SUBJECT TO
1)!If "ij" has three digits and starts with 1 or 2, X defines origin's name in first two digits while K defines origin's name in the first digit.
X11 + X12 + X13 + X14 + X15 + X16 + X17 + X18 + X19 + X110 + K111 + K112 + K113 + K114 + K115 + K116 + K117 + K118 + K119 + K120 + K121 + K122 + K123 + K124 + K125 + K126 = 1
X21 + X22 + X23 + X24 + X25 + X26 + X27 + X28 + X29 + X210 + K211 + K212 + K213 + K214 + K215 + K216 + K217 + K218 + K219 + K220 + K221 + K222 + K223 + K224 + K225 + K226 = 1
X31 + X32 + X33 + X34 + X35 + X36 + X37 + X38 + X39 + X310 + X311 + X312 + X313 + X314 + X315 + X316 + X317 + X318 + X319 + X320 + X321 + X322 + X323 + X324 + X325 + X326 = 1
X41 + X42 + X43 + X44 + X45 + X46 + X47 + X48 + X49 + X410 + X411 + X412 + X413 + X414 + X415 + X416 + X417 + X418 + X419 + X420 + X421 + X422 + X423 + X424 + X425 + X426 = 1
X51 + X52 + X53 + X54 + X55 + X56 + X57 + X58 + X59 + X510 + X511 + X512 + X513 + X514 + X515 + X516 + X517 + X518 + X519 + X520 + X521 + X522 + X523 + X524 + X525 + X526 = 1
X61 + X62 + X63 + X64 + X65 + X66 + X67 + X68 + X69 + X610 + X611 + X612 + X613 + X614 + X615 + X616 + X617 + X618 + X619 + X620 + X621 + X622 + X623 + X624 + X625 + X626 = 1
X71 + X72 + X73 + X74 + X75 + X76 + X77 + X78 + X79 + X710 + X711 + X712 + X713 + X714 + X715 + X716 + X717 + X718 + X719 + X720 + X721 + X722 + X723 + X724 + X725 + X726 = 1
X81 + X82 + X83 + X84 + X85 + X86 + X87 + X88 + X89 + X810 + X811 + X812 + X813 + X814 + X815 + X816 + X817 + X818 + X819 + X820 + X821 + X822 + X823 + X824 + X825 + X826 = 1

```
X91 + X92 + X93 + X94 + X95 + X96 + X97 + X98 + X99 + X910 + X911 + X912 + X913 + X914
+ X915 + X916 + X917 + X918 + X919 + X920 + X921 + X922 + X923 + X924 + X925 + X926 =
1
X101 + X102 + X103 + X104 + X105 + X106 + X107 + X108 + X109 + X1010 + X1011 + X1012 +
X1013 + X1014 + X1015 + X1016 + X1017 + X1018 + X1019 + X1020 + X1021 + X1022 + X1023
+ X1024 + X1025+ X1026= 1
X111 + X112 + X113 + X114 + X115 + X116 + X117 + X118 + X119 + X1110 + X1111 + X1112 +
X1113 + X1114 + X1115 + X1116 + X1117 + X1118 + X1119 + X1120 + X1121 + X1122 + X1123
+ X1124 + X1125+ X1126= 1
X121 + X122 + X123 + X124 + X125 + X126 + X127 + X128 + X129 + X1210 + X1211 + X1212 +
X1213 + X1214 + X1215 + X1216 + X1217 + X1218 + X1219 + X1220 + X1221 + X1222 + X1223
+ X1224 + X1225+ X1226= 1
X131 + X132 + X133 + X134 + X135 + X136 + X137 + X138 + X139 + X1310 + X1311 + X1312 +
X1313 + X1314 + X1315 + X1316 + X1317 + X1318 + X1319 + X1320 + X1321 + X1322 + X1323
+ X1324 + X1325+ X1326= 1
X141 + X142 + X143 + X144 + X145 + X146 + X147 + X148 + X149 + X1410 + X1411 + X1412 +
X1413 + X1414 + X1415 + X1416 + X1417 + X1418 + X1419 + X1420 + X1421 + X1422 + X1423
+ X1424 + X1425+ X1426= 1
X151 + X152 + X153 + X154 + X155 + X156 + X157 + X158 + X159 + X1510 + X1511 + X1512 +
X1513 + X1514 + X1515 + X1516 + X1517 + X1518 + X1519 + X1520 + X1521 + X1522 + X1523
+ X1524 + X1525+ X1526= 1
X161 + X162 + X163 + X164 + X165 + X166 + X167 + X168 + X169 + X1610 + X1611 + X1612 +
X1613 + X1614 + X1615 + X1616 + X1617 + X1618 + X1619 + X1620 + X1621 + X1622 + X1623
+ X1624 + X1625+ X1626= 1
X171 + X172 + X173 + X174 + X175 + X176 + X177 + X178 + X179 + X1710 + X1711 + X1712 +
X1713 + X1714 + X1715 + X1716 + X1717 + X1718 + X1719 + X1720 + X1721 + X1722 + X1723
+ X1724 + X1725+ X1726= 1
X181 + X182 + X183 + X184 + X185 + X186 + X187 + X188 + X189 + X1810 + X1811 + X1812 +
X1813 + X1814 + X1815 + X1816 + X1817 + X1818 + X1819 + X1820 + X1821 + X1822 + X1823
+ X1824 + X1825+ X1826= 1
X191 + X192 + X193 + X194 + X195 + X196 + X197 + X198 + X199 + X1910 + X1911 + X1912 +
X1913 + X1914 + X1915 + X1916 + X1917 + X1918 + X1919 + X1920 + X1921 + X1922 + X1923
+ X1924 + X1925+ X1926= 1
X201 + X202 + X203 + X204 + X205 + X206 + X207 + X208 + X209 + X2010 + X2011 + X2012 +
X2013 + X2014 + X2015 + X2016 + X2017 + X2018 + X2019 + X2020 + X2021 + X2022 + X2023
+ X2024 + X2025+ X2026= 1
X211 + X212 + X213 + X214 + X215 + X216 + X217 + X218 + X219 + X2110 + X2111 + X2112 +
X2113 + X2114 + X2115 + X2116 + X2117 + X2118 + X2119 + X2120 + X2121 + X2122 + X2123
+ X2124 + X2125+ X2126= 1
X221 + X222 + X223 + X224 + X225 + X226 + X227 + X228 + X229 + X2210 + X2211 + X2212 +
X2213 + X2214 + X2215 + X2216 + X2217 + X2218 + X2219 + X2220 + X2221 + X2222 + X2223
+ X2224 + X2225+ X2226= 1
X231 + X232 + X233 + X234 + X235 + X236 + X237 + X238 + X239 + X2310 + X2311 + X2312 +
X2313 + X2314 + X2315 + X2316 + X2317 + X2318 + X2319 + X2320 + X2321 + X2322 + X2323
+ X2324 + X2325+ X2326= 1
X241 + X242 + X243 + X244 + X245 + X246 + X247 + X248 + X249 + X2410 + X2411 + X2412 +
X2413 + X2414 + X2415 + X2416 + X2417 + X2418 + X2419 + X2420 + X2421 + X2422 + X2423
+ X2424 + X2425+ X2426= 1
X251 + X252 + X253 + X254 + X255 + X256 + X257 + X258 + X259 + X2510 + X2511 + X2512 +
X2513 + X2514 + X2515 + X2516 + X2517 + X2518 + X2519 + X2520 + X2521 + X2522 + X2523
+ X2524 + X2525+ X2526= 1

2) ! Yj stands for Xj in the mathematical formulation.
X11 - Y1 <= 0
X12 - Y2 <= 0
X13 - Y3 <= 0
X14 - Y4 <= 0
X15 - Y5 <= 0
X16 - Y6 <= 0
X17 - Y7 <= 0
X18 - Y8 <= 0
X19 - Y9 <= 0
X110 - Y10 <= 0
```

```
K111 - Y11 <= 0
K112 - Y12 <= 0
K113 - Y13 <= 0
K114 - Y14 <= 0
K115 - Y15 <= 0
K116 - Y16 <= 0
K117 - Y17 <= 0
K118 - Y18 <= 0
K119 - Y19 <= 0
K120 - Y20 <= 0
K121 - Y21 <= 0
K122 - Y22 <= 0
K123 - Y23 <= 0
K124 - Y24 <= 0
K125 - Y25 <= 0
K126 - Y26 <= 0
X21 - Y1 <= 0
X22 - Y2 <= 0
X23 - Y3 <= 0
X24 - Y4 <= 0
X25 - Y5 <= 0
X26 - Y6 <= 0
X27 - Y7 <= 0
X28 - Y8 <= 0
X29 - Y9 <= 0
X210 - Y10 <= 0
K211 - Y11 <= 0
K212 - Y12 <= 0
K213 - Y13 <= 0
K214 - Y14 <= 0
K215 - Y15 <= 0
K216 - Y16 <= 0
K217 - Y17 <= 0
K218 - Y18 <= 0
K219 - Y19 <= 0
K220 - Y20 <= 0
K221 - Y21 <= 0
K222 - Y22 <= 0
K223 - Y23 <= 0
K224 - Y24 <= 0
K225 - Y25 <= 0
K226 - Y26 <= 0
X31 - Y1 <= 0
X32 - Y2 <= 0
X33 - Y3 <= 0
X34 - Y4 <= 0
X35 - Y5 <= 0
X36 - Y6 <= 0
X37 - Y7 <= 0
X38 - Y8 <= 0
X39 - Y9 <= 0
X310 - Y10 <= 0
X311 - Y11 <= 0
X312 - Y12 <= 0
X313 - Y13 <= 0
X314 - Y14 <= 0
X315 - Y15 <= 0
X316 - Y16 <= 0
X317 - Y17 <= 0
X318 - Y18 <= 0
X319 - Y19 <= 0
X320 - Y20 <= 0
X321 - Y21 <= 0
```

X322 - Y22 <= 0
X323 - Y23 <= 0
X324 - Y24 <= 0
X325 - Y25 <= 0
X326 - Y26 <= 0
X41 - Y1 <= 0
X42 - Y2 <= 0
X43 - Y3 <= 0
X44 - Y4 <= 0
X45 - Y5 <= 0
X46 - Y6 <= 0
X47 - Y7 <= 0
X48 - Y8 <= 0
X49 - Y9 <= 0
X410 - Y10 <= 0
X411 - Y11 <= 0
X412 - Y12 <= 0
X413 - Y13 <= 0
X414 - Y14 <= 0
X415 - Y15 <= 0
X416 - Y16 <= 0
X417 - Y17 <= 0
X418 - Y18 <= 0
X419 - Y19 <= 0
X420 - Y20 <= 0
X421 - Y21 <= 0
X422 - Y22 <= 0
X423 - Y23 <= 0
X424 - Y24 <= 0
X425 - Y25 <= 0
X426 - Y26 <= 0
X51 - Y1 <= 0
X52 - Y2 <= 0
X53 - Y3 <= 0
X54 - Y4 <= 0
X55 - Y5 <= 0
X56 - Y6 <= 0
X57 - Y7 <= 0
X58 - Y8 <= 0
X59 - Y9 <= 0
X510 - Y10 <= 0
X511 - Y11 <= 0
X512 - Y12 <= 0
X513 - Y13 <= 0
X514 - Y14 <= 0
X515 - Y15 <= 0
X516 - Y16 <= 0
X517 - Y17 <= 0
X518 - Y18 <= 0
X519 - Y19 <= 0
X520 - Y20 <= 0
X521 - Y21 <= 0
X522 - Y22 <= 0
X523 - Y23 <= 0
X524 - Y24 <= 0
X525 - Y25 <= 0
X526 - Y26 <= 0
X61 - Y1 <= 0
X62 - Y2 <= 0
X63 - Y3 <= 0
X64 - Y4 <= 0
X65 - Y5 <= 0
X66 - Y6 <= 0

```
X67 - Y7 <= 0
X68 - Y8 <= 0
X69 - Y9 <= 0
X610 - Y10 <= 0
X611 - Y11 <= 0
X612 - Y12 <= 0
X613 - Y13 <= 0
X614 - Y14 <= 0
X615 - Y15 <= 0
X616 - Y16 <= 0
X617 - Y17 <= 0
X618 - Y18 <= 0
X619 - Y19 <= 0
X620 - Y20 <= 0
X621 - Y21 <= 0
X622 - Y22 <= 0
X623 - Y23 <= 0
X624 - Y24 <= 0
X625 - Y25 <= 0
X626 - Y26 <= 06
X71 - Y1 <= 0
X72 - Y2 <= 0
X73 - Y3 <= 0
X74 - Y4 <= 0
X75 - Y5 <= 0
X76 - Y6 <= 0
X77 - Y7 <= 0
X78 - Y8 <= 0
X79 - Y9 <= 0
X710 - Y10 <= 0
X711 - Y11 <= 0
X712 - Y12 <= 0
X713 - Y13 <= 0
X714 - Y14 <= 0
X715 - Y15 <= 0
X716 - Y16 <= 0
X717 - Y17 <= 0
X718 - Y18 <= 0
X719 - Y19 <= 0
X720 - Y20 <= 0
X721 - Y21 <= 0
X722 - Y22 <= 0
X723 - Y23 <= 0
X724 - Y24 <= 0
X725 - Y25 <= 0
X726 - Y26 <= 0
X81 - Y1 <= 0
X82 - Y2 <= 0
X83 - Y3 <= 0
X84 - Y4 <= 0
X85 - Y5 <= 0
X86 - Y6 <= 0
X87 - Y7 <= 0
X88 - Y8 <= 0
X89 - Y9 <= 0
X810 - Y10 <= 0
X811 - Y11 <= 0
X812 - Y12 <= 0
X813 - Y13 <= 0
X814 - Y14 <= 0
X815 - Y15 <= 0
X816 - Y16 <= 0
X817 - Y17 <= 0
```

```
X818 - Y18 <= 0
X819 - Y19 <= 0
X820 - Y20 <= 0
X821 - Y21 <= 0
X822 - Y22 <= 0
X823 - Y23 <= 0
X824 - Y24 <= 0
X825 - Y25 <= 0
X826 - Y26 <= 0
X91 - Y1 <= 0
X92 - Y2 <= 0
X93 - Y3 <= 0
X94 - Y4 <= 0
X95 - Y5 <= 0
X96 - Y6 <= 0
X97 - Y7 <= 0
X98 - Y8 <= 0
X99 - Y9 <= 0
X910 - Y10 <= 0
X911 - Y11 <= 0
X912 - Y12 <= 0
X913 - Y13 <= 0
X914 - Y14 <= 0
X915 - Y15 <= 0
X916 - Y16 <= 0
X917 - Y17 <= 0
X918 - Y18 <= 0
X919 - Y19 <= 0
X920 - Y20 <= 0
X921 - Y21 <= 0
X922 - Y22 <= 0
X923 - Y23 <= 0
X924 - Y24 <= 0
X925 - Y25 <= 0
X926 - Y26 <= 0
X101 - Y1 <= 0
X102 - Y2 <= 0
X103 - Y3 <= 0
X104 - Y4 <= 0
X105 - Y5 <= 0
X106 - Y6 <= 0
X107 - Y7 <= 0
X108 - Y8 <= 0
X109 - Y9 <= 0
X1010 - Y10 <= 0
X1011 - Y11 <= 0
X1012 - Y12 <= 0
X1013 - Y13 <= 0
X1014 - Y14 <= 0
X1015 - Y15 <= 0
X1016 - Y16 <= 0
X1017 - Y17 <= 0
X1018 - Y18 <= 0
X1019 - Y19 <= 0
X1020 - Y20 <= 0
X1021 - Y21 <= 0
X1022 - Y22 <= 0
X1023 - Y23 <= 0
X1024 - Y24 <= 0
X1025 - Y25 <= 0
X1026 - Y26 <= 0
X111 - Y1 <= 0
X112 - Y2 <= 0
```

```
X113 - Y3 <= 0
X114 - Y4 <= 0
X115 - Y5 <= 0
X116 - Y6 <= 0
X117 - Y7 <= 0
X118 - Y8 <= 0
X119 - Y9 <= 0
X1110 - Y10 <= 0
X1111 - Y11 <= 0
X1112 - Y12 <= 0
X1113 - Y13 <= 0
X1114 - Y14 <= 0
X1115 - Y15 <= 0
X1116 - Y16 <= 0
X1117 - Y17 <= 0
X1118 - Y18 <= 0
X1119 - Y19 <= 0
X1120 - Y20 <= 0
X1121 - Y21 <= 0
X1122 - Y22 <= 0
X1123 - Y23 <= 0
X1124 - Y24 <= 0
X1125 - Y25 <= 0
X1126 - Y26 <= 0
X121 - Y1 <= 0
X122 - Y2 <= 0
X123 - Y3 <= 0
X124 - Y4 <= 0
X125 - Y5 <= 0
X126 - Y6 <= 0
X127 - Y7 <= 0
X128 - Y8 <= 0
X129 - Y9 <= 0
X1210 - Y10 <= 0
X1211 - Y11 <= 0
X1212 - Y12 <= 0
X1213 - Y13 <= 0
X1214 - Y14 <= 0
X1215 - Y15 <= 0
X1216 - Y16 <= 0
X1217 - Y17 <= 0
X1218 - Y18 <= 0
X1219 - Y19 <= 0
X1220 - Y20 <= 0
X1221 - Y21 <= 0
X1222 - Y22 <= 0
X1223 - Y23 <= 0
X1224 - Y24 <= 0
X1225 - Y25 <= 0
X1226 - Y26 <= 0
X131 - Y1 <= 0
X132 - Y2 <= 0
X133 - Y3 <= 0
X134 - Y4 <= 0
X135 - Y5 <= 0
X136 - Y6 <= 0
X137 - Y7 <= 0
X138 - Y8 <= 0
X139 - Y9 <= 0
X1310 - Y10 <= 0
X1311 - Y11 <= 0
X1312 - Y12 <= 0
X1313 - Y13 <= 0
```

```
X1314 - Y14 <= 0
X1315 - Y15 <= 0
X1316 - Y16 <= 0
X1317 - Y17 <= 0
X1318 - Y18 <= 0
X1319 - Y19 <= 0
X1320 - Y20 <= 0
X1321 - Y21 <= 0
X1322 - Y22 <= 0
X1323 - Y23 <= 0
X1324 - Y24 <= 0
X1325 - Y25 <= 0
X1326 - Y26 <= 0
X141 - Y1 <= 0
X142 - Y2 <= 0
X143 - Y3 <= 0
X144 - Y4 <= 0
X145 - Y5 <= 0
X146 - Y6 <= 0
X147 - Y7 <= 0
X148 - Y8 <= 0
X149 - Y9 <= 0
X1410 - Y10 <= 0
X1411 - Y11 <= 0
X1412 - Y12 <= 0
X1413 - Y13 <= 0
X1414 - Y14 <= 0
X1415 - Y15 <= 0
X1416 - Y16 <= 0
X1417 - Y17 <= 0
X1418 - Y18 <= 0
X1419 - Y19 <= 0
X1420 - Y20 <= 0
X1421 - Y21 <= 0
X1422 - Y22 <= 0
X1423 - Y23 <= 0
X1424 - Y24 <= 0
X1425 - Y25 <= 0
X1426 - Y26 <= 0
X151 - Y1 <= 0
X152 - Y2 <= 0
X153 - Y3 <= 0
X154 - Y4 <= 0
X155 - Y5 <= 0
X156 - Y6 <= 0
X157 - Y7 <= 0
X158 - Y8 <= 0
X159 - Y9 <= 0
X1510 - Y10 <= 0
X1511 - Y11 <= 0
X1512 - Y12 <= 0
X1513 - Y13 <= 0
X1514 - Y14 <= 0
X1515 - Y15 <= 0
X1516 - Y16 <= 0
X1517 - Y17 <= 0
X1518 - Y18 <= 0
X1519 - Y19 <= 0
X1520 - Y20 <= 0
X1521 - Y21 <= 0
X1522 - Y22 <= 0
X1523 - Y23 <= 0
X1524 - Y24 <= 0
```

```
X1525 - Y25 <= 0
X1526 - Y26 <= 0
X161 - Y1 <= 0
X162 - Y2 <= 0
X163 - Y3 <= 0
X164 - Y4 <= 0
X165 - Y5 <= 0
X166 - Y6 <= 0
X167 - Y7 <= 0
X168 - Y8 <= 0
X169 - Y9 <= 0
X1610 - Y10 <= 0
X1611 - Y11 <= 0
X1612 - Y12 <= 0
X1613 - Y13 <= 0
X1614 - Y14 <= 0
X1615 - Y15 <= 0
X1616 - Y16 <= 0
X1617 - Y17 <= 0
X1618 - Y18 <= 0
X1619 - Y19 <= 0
X1620 - Y20 <= 0
X1621 - Y21 <= 0
X1622 - Y22 <= 0
X1623 - Y23 <= 0
X1624 - Y24 <= 0
X1625 - Y25 <= 0
X1626 - Y26 <= 0
X171 - Y1 <= 0
X172 - Y2 <= 0
X173 - Y3 <= 0
X174 - Y4 <= 0
X175 - Y5 <= 0
X176 - Y6 <= 0
X177 - Y7 <= 0
X178 - Y8 <= 0
X179 - Y9 <= 0
X1710 - Y10 <= 0
X1711 - Y11 <= 0
X1712 - Y12 <= 0
X1713 - Y13 <= 0
X1714 - Y14 <= 0
X1715 - Y15 <= 0
X1716 - Y16 <= 0
X1717 - Y17 <= 0
X1718 - Y18 <= 0
X1719 - Y19 <= 0
X1720 - Y20 <= 0
X1721 - Y21 <= 0
X1722 - Y22 <= 0
X1723 - Y23 <= 0
X1724 - Y24 <= 0
X1725 - Y25 <= 0
X1726 - Y26 <= 0
X181 - Y1 <= 0
X182 - Y2 <= 0
X183 - Y3 <= 0
X184 - Y4 <= 0
X185 - Y5 <= 0
X186 - Y6 <= 0
X187 - Y7 <= 0
X188 - Y8 <= 0
X189 - Y9 <= 0
```

```
X1810 - Y10 <= 0
X1811 - Y11 <= 0
X1812 - Y12 <= 0
X1813 - Y13 <= 0
X1814 - Y14 <= 0
X1815 - Y15 <= 0
X1816 - Y16 <= 0
X1817 - Y17 <= 0
X1818 - Y18 <= 0
X1819 - Y19 <= 0
X1820 - Y20 <= 0
X1821 - Y21 <= 0
X1822 - Y22 <= 0
X1823 - Y23 <= 0
X1824 - Y24 <= 0
X1825 - Y25 <= 0
X1826 - Y26 <= 0
X191 - Y1 <= 0
X192 - Y2 <= 0
X193 - Y3 <= 0
X194 - Y4 <= 0
X195 - Y5 <= 0
X196 - Y6 <= 0
X197 - Y7 <= 0
X198 - Y8 <= 0
X199 - Y9 <= 0
X1910 - Y10 <= 0
X1911 - Y11 <= 0
X1912 - Y12 <= 0
X1913 - Y13 <= 0
X1914 - Y14 <= 0
X1915 - Y15 <= 0
X1916 - Y16 <= 0
X1917 - Y17 <= 0
X1918 - Y18 <= 0
X1919 - Y19 <= 0
X1920 - Y20 <= 0
X1921 - Y21 <= 0
X1922 - Y22 <= 0
X1923 - Y23 <= 0
X1924 - Y24 <= 0
X1925 - Y25 <= 0
X1926 - Y26 <= 0
X201 - Y1 <= 0
X202 - Y2 <= 0
X203 - Y3 <= 0
X204 - Y4 <= 0
X205 - Y5 <= 0
X206 - Y6 <= 0
X207 - Y7 <= 0
X208 - Y8 <= 0
X209 - Y9 <= 0
X2010 - Y10 <= 0
X2011 - Y11 <= 0
X2012 - Y12 <= 0
X2013 - Y13 <= 0
X2014 - Y14 <= 0
X2015 - Y15 <= 0
X2016 - Y16 <= 0
X2017 - Y17 <= 0
X2018 - Y18 <= 0
X2019 - Y19 <= 0
X2020 - Y20 <= 0
```

```
X2021 - Y21 <= 0
X2022 - Y22 <= 0
X2023 - Y23 <= 0
X2024 - Y24 <= 0
X2025 - Y25 <= 0
X2126 - Y26 <= 0
X211 - Y1 <= 0
X212 - Y2 <= 0
X213 - Y3 <= 0
X214 - Y4 <= 0
X215 - Y5 <= 0
X216 - Y6 <= 0
X217 - Y7 <= 0
X218 - Y8 <= 0
X219 - Y9 <= 0
X2110 - Y10 <= 0
X2111 - Y11 <= 0
X2112 - Y12 <= 0
X2113 - Y13 <= 0
X2114 - Y14 <= 0
X2115 - Y15 <= 0
X2116 - Y16 <= 0
X2117 - Y17 <= 0
X2118 - Y18 <= 0
X2119 - Y19 <= 0
X2120 - Y20 <= 0
X2121 - Y21 <= 0
X2122 - Y22 <= 0
X2123 - Y23 <= 0
X2124 - Y24 <= 0
X2125 - Y25 <= 0
X2126 - Y26 <= 0
X221 - Y1 <= 0
X222 - Y2 <= 0
X223 - Y3 <= 0
X224 - Y4 <= 0
X225 - Y5 <= 0
X226 - Y6 <= 0
X227 - Y7 <= 0
X228 - Y8 <= 0
X229 - Y9 <= 0
X2210 - Y10 <= 0
X2211 - Y11 <= 0
X2212 - Y12 <= 0
X2213 - Y13 <= 0
X2214 - Y14 <= 0
X2215 - Y15 <= 0
X2216 - Y16 <= 0
X2217 - Y17 <= 0
X2218 - Y18 <= 0
X2219 - Y19 <= 0
X2220 - Y20 <= 0
X2221 - Y21 <= 0
X2222 - Y22 <= 0
X2223 - Y23 <= 0
X2224 - Y24 <= 0
X2225 - Y25 <= 0
X2226 - Y26 <= 0
X231 - Y1 <= 0
X232 - Y2 <= 0
X233 - Y3 <= 0
X234 - Y4 <= 0
X235 - Y5 <= 0
```

```
X236 - Y6 <= 0
X237 - Y7 <= 0
X238 - Y8 <= 0
X239 - Y9 <= 0
X2310 - Y10 <= 0
X2311 - Y11 <= 0
X2312 - Y12 <= 0
X2313 - Y13 <= 0
X2314 - Y14 <= 0
X2315 - Y15 <= 0
X2316 - Y16 <= 0
X2317 - Y17 <= 0
X2318 - Y18 <= 0
X2319 - Y19 <= 0
X2320 - Y20 <= 0
X2321 - Y21 <= 0
X2322 - Y22 <= 0
X2323 - Y23 <= 0
X2324 - Y24 <= 0
X2325 - Y25 <= 0
X2326 - Y26 <= 0
X241 - Y1 <= 0
X242 - Y2 <= 0
X243 - Y3 <= 0
X244 - Y4 <= 0
X245 - Y5 <= 0
X246 - Y6 <= 0
X247 - Y7 <= 0
X248 - Y8 <= 0
X249 - Y9 <= 0
X2410 - Y10 <= 0
X2411 - Y11 <= 0
X2412 - Y12 <= 0
X2413 - Y13 <= 0
X2414 - Y14 <= 0
X2415 - Y15 <= 0
X2416 - Y16 <= 0
X2417 - Y17 <= 0
X2418 - Y18 <= 0
X2419 - Y19 <= 0
X2420 - Y20 <= 0
X2421 - Y21 <= 0
X2422 - Y22 <= 0
X2423 - Y23 <= 0
X2424 - Y24 <= 0
X2425 - Y25 <= 0
X2426 - Y26 <= 0
X251 - Y1 <= 0
X252 - Y2 <= 0
X253 - Y3 <= 0
X254 - Y4 <= 0
X255 - Y5 <= 0
X256 - Y6 <= 0
X257 - Y7 <= 0
X258 - Y8 <= 0
X259 - Y9 <= 0
X2510 - Y10 <= 0
X2511 - Y11 <= 0
X2512 - Y12 <= 0
X2513 - Y13 <= 0
X2514 - Y14 <= 0
X2515 - Y15 <= 0
X2516 - Y16 <= 0
```

```
X2517 - Y17 <= 0
X2518 - Y18 <= 0
X2519 - Y19 <= 0
X2520 - Y20 <= 0
X2521 - Y21 <= 0
X2522 - Y22 <= 0
X2523 - Y23 <= 0
X2524 - Y24 <= 0
X2525 - Y25 <= 0
X2526 - Y26 <= 0

3) Y1 + Y2 + Y3 + Y4 + Y5 + Y6 + Y7 + Y8 + Y9 + Y10 + Y11 + Y12 + Y13 + Y14 + Y15 +
Y16 + Y17 + Y18 + Y19 + Y20 + Y21 + Y22+ Y23 + Y24 + Y25 + Y26 = 5

4) Y1 = 0
Y2 = 0
Y3 = 0
Y4 = 0
Y7 = 0
Y8 = 0
Y12 = 0
Y14 = 0
Y15 = 0
Y17 = 0
Y18 = 0
Y19 = 0
Y20 = 0
Y22 = 0
Y23 = 0
Y24 = 0
Y25 = 0

END
[Definition of binary integer variables like INT Y1]
```

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