The Application of the Systems Engineering Process to the Development of a Global Communications System Using Portable Phones

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Systems Engineering
(Abstract)

Telecommunications capabilities have increased
dramatically in recent years. Especially significant is the
introduction and tremendous growth of mobile telephone
communications. Given the limitations of current mobile
phone communications and the need for truly global person-
to-person capabilities, an enhanced satellite-based system
is presented as a feasible means to link portable telephones
throughout the world.

Using systems engineering and the systems approach, the
choice of using a satellite system vice other methods is
made from a feasibility analysis. Following this choice,
operational requirements are established. Based upon these
requirements, two different satellite constellations are
presented for consideration: a three-satellite
geosynchronous constellation and a multi-satellite low earth
orbiting (LEO) constellation. The advantages and disadvantages of each configuration are explored and the LEO constellation is chosen. Throughout the paper, systems engineering and its methodologies are used to illustrate how such a system might be developed using the systems approach.
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Introduction

The need for personal communications between two people separated by some distance has been the proverbial "mother" of many inventions. For millenniums, the only manner in which to communicate with those out of earshot was via the written word. This all changed with the invention of the telegraph by Samuel Morse in 1837. However, the telegraph did not make one-to-one communications simple since a cumbersome code was required. The device that truly revolutionized person-to-person communications was Alexander Graham Bell's 1876 invention -- the telephone.

Although numerous improvements were made to the telephone in the years following 1876, the device remained basically the same for the next century -- a handset directly attached to a fixed wire-based network. Because of this, the user was not allowed to venture away from the wire network any further than the phone cord would allow. Improvements in telephone communications were made, of course. For instance, the availability of phone service increased dramatically, but global connections were limited by the absence of networks in hard-to-reach places (and this is a problem that persists today). However, recent technological advancements have changed the telephone from its somewhat stagnated development. It is within the last decade that telephone users have been freed from the bounds
of the phone cord, and this freedom has caused a revolution in personal communications.

Within the last ten years, cordless phones and cellular phones have exploded onto the market. The cordless phone allows the user to move about a limited area with a light, handheld unit. A cellular phone allows the user to move about in a much larger area, but normally the phone is attached to a car. Some mobile phones provide the convenience of the cellular phone and the cordless phone, but these phones are expensive and, relative to the cordless phones, heavy. Despite the limitations, the cellular-type phones have become increasingly popular and the demand shows no signs of leveling off. Now there are proposals to combine the best attributes of fixed, mobile, cellular, and cordless phones and take portable telephone communications a giant step further.

Many communication companies are working on systems that will provide truly global communications using portable, almost pocket-sized phones by the year 2000. The predominant method of implementing this method is via a satellite network. Some companies such as the American Mobile Satellite Corporation (AMSC) propose using a geosynchronous satellite constellation, while other companies such as Motorola are working on a Low Earth Orbiting (LEO) satellite constellation. Regardless of which
configuration is implemented, the project will be extremely complex and the costs involved quite large. Stumbling haphazardly into the development of such a system would cause prohibitively large amounts of money to be spent and would result in a system characterized by poor performance. To ensure that the development of the system is properly coordinated, a systems approach should be used.

This paper will outline a systems approach to the proposed global communications system using portable phones. The goal of the paper is to briefly illustrate the process that should be followed to ensure that the resultant system best satisfies the identified need. This paper by no means represents an actual, functioning system development of the global communications system; to perform such a task would require many engineers from many disciplines working, literally, many years. Additionally, much of the necessary technical information is company proprietary and can not be firmly established. What this paper does do is give the reader a sense of what issues must be addressed as a major system such as this one is developed from its conception.

This paper is basically divided into two parts. The first part is a brief synopsis of systems engineering, what the systems approach is, and how the systems approach relates to the topic addressed in this paper. Although not large, this systems section is needed to give the reader
guidance for what is to follow. The second part of this paper is the abbreviated systems analysis of the Global Communications System Using Portable Phones (GCSUPP). The systems analysis consists of a Definition of Need (section 1.0), a Market Analysis (2.0), a Feasibility Analysis (3.0), an Operational Requirements section (4.0), a Maintenance Concept (5.0), a Conceptual Design section (6.0), a Detailed Requirements section (7.0), and a System Functional Flow section (8.0). A bibliography is presented at the end of the paper.
Systems Engineering and the Systems Approach

Systems engineering is not an engineering discipline in the traditional sense. Instead of focusing on a technical specialty, system engineering ensures that all aspects of a system are properly integrated and function as a single entity [Blanchard, "Systems," p.13]. Its role is "to solve problems involving technology in the context of the environment and the society in which they exist using methodologies of current and potential usefulness in decision making" [Drew (Graphic), p. 1]. The systems approach is the process employed in the evolution of a system from the time that a need is identified until the system is used by the customer. As Dr. Donald Drew states in his book System Dynamics: Modeling and Applications.

The systems approach strives to be logical, consistent, [and] objective ... in analyzing systems and solving problems. It recognizes the need to make compromises and tradeoffs among the system factors. It facilitates the selection of the best approach from the many alternatives [Drew (System), p. 5].

This process includes defining the need for the system, ensuring that there is in fact a market for the system and what type of market exists, ensuring that it is feasible to
develop a system that will satisfy the need, establishing requirements that must be met as well as a maintenance concept, and designing the system. A full-blown systems engineering process also involves synthesis, allocation, optimization, detailed design, test and evaluation, production, and utilization. To develop the best possible system, system engineering integrates reliability, maintainability, human factors, safety, and logistic elements into the engineering design.

One of the main characteristics of the systems approach is observing the system as a whole rather than focusing on an individual component of the system. As one author states,

The greatest asset of the [systems approach] is that it forces comprehensive consideration of the system rather than singling out a particular facet and trying to understand it alone [Drev. (System), p. 16].

This is known as a top-down approach and treats the system, first and foremost, as a black box. Of secondary concern is how the subsystems within the black box function. To put this another way, systems engineering is more interested in putting things together than in taking them apart [Blanchard, "Systems," p. 12]. The reason this is needed is
that the condition of separate components functioning optimally on their own does not necessarily imply that the system will perform optimally. The goal is to produce an effective system, not to produce a series of components that function great on their own but do not assimilate well to the system.

Another characteristic of system engineering is using a team approach to all aspects of the system's development. For example, instead of having electrical engineers exclusively responsible for a component, engineers from different disciplines are involved to ensure the component meets reliability requirements, maintainability requirements, interface requirements, performance requirements, etc. Systems engineering's role is to bridge the gap between the various disciplines. This is illustrated in Figure S1.
Figure S1. Example of Systems Engineering and Its Relationship to Other Engineering Disciplines
Making front-end decisions is another facet of the systems approach. The system should not be designed and then address issues pertaining to topics such as economic factors, ecological factors, political factors, and societal factors. These issues must be addressed during the initial phases of system development if the proper system is to be designed and implemented. Failure to consider these factors often results in numerous redesigns, cost over-runs, and even the system not ever being implemented. The more expensive the system, the more important these front-end decisions become.

Yet another aspect of the systems approach is the process of feedback. The systems engineering process is continuous, iterative, and incorporates the feedback actions necessary to ensure convergence of the system [Blanchard, "Systems," p. 23]. In other words, the system's evolution never stops -- for instance, the requirements drive the conceptual design, but as the early stages of the design progresses, the requirements may be forced to change.

In order to incorporate the systems approach into the actual development of a system, the Systems Engineer is provided numerous tools and techniques. These tools can be both physical and conceptual. Regardless of their characteristics, their purpose is the same: to ensure the goal of the proper balance between operational, economic,
and logistical factors is met and that the optimal system is developed [Blanchard, "Logistics", p. 9].

The conceptual tools used in the systems engineering process consist primarily of numerous reviews. The purpose of these reviews is to evaluate each major stage in the system's development to ensure that the best overall system is being developed. These reviews provide a common baseline for all project personnel as well as an excellent communication forum. Additionally, reviews provide a means for solving interface problems and for recording what decisions were made and why. Generally, there are four types of reviews: the conceptual design review (which is primarily a review of the system's requirements), the system design review, the equipment design review, and the critical design review. Other more specific reviews include equipment-software design reviews, test and evaluation plan reviews, and feasibility reviews.

Documents are among the physical tools used in the system engineering process. For instance, the System Specification (Type A) document is a technical document that results from early system planning. It provides information concerning topics such as the system's operational requirements and physical characteristics and this information is then used as the basis for future, more detailed specifications. In general, the documents serve to
guide the system developers when questions arise about issues such as standards and reliability criteria.

Another physical tool is the computer. Recent advances in computer hardware and software have made concurrent engineering via computer possible. The development of compatible CAD (Computer-Aided Design), CAM (Computer-Aided Manufacturing), and CALS (Computer-Aided Acquisition and Logistic Support) packages has allowed engineers designing the system to quickly address different issues and, when a change is made to a portion of the system, have that change reflected throughout the system. This improves the communication between the designers of the various components and ensures the various engineers are all working from a common baseline. Together, these computer tools are known as MacroCAD and foster the selection of the best system configuration.

Models are another tool that is available to the Systems Engineer. These models can be a part of the MacroCAD utility, or they can take different forms. Using a model yields design or operational decisions in less time and at less cost than direct manipulation of the system itself [Blanchard, "Systems," p. 124]. Unlike scientific models that are concerned with systems in the natural world, engineering models are concerned with man-made systems
(although the scientific models serve as a foundation for the engineering models).

Models can be either physical, analog, schematic, or mathematical in nature. A physical model looks like what it represents, such as a miniature car for an automotive design. An analog model is represented by physical elements. For example, a mechanical system might be represented by an electrical circuit. A schematic model is basically a chart or diagram that represents relationships among various facets of the system. Finally, a mathematical model is a series of related equations and formulas that are used to help predict the system's performance [Blanchard, "Systems," p. 125-126]. An example of a mathematical model is a system dynamics model using the DYNAMO (DYNAmic M0deling) software.
Systems Engineering and the Global Communications System

Using Portable Phones

The GCSUPP is a major undertaking. The goal is to provide communications between any two points on the globe; for example, a caller in New York City could call up someone in a canoe on the Nile River. Developing a system of this magnitude requires many people from numerous disciplines including electrical engineering, marketing, international law, and even political science to name just a few. The development of the system will require a great deal of time and money. Thus, it is essential to employ a top-down approach to the system's development and ensure that when the actual system design begins, as many front-end issues have been addressed as possible.

As stated in the introduction, doing a full scale system development of a project of this magnitude is impossible to accomplish by one person working a few months with little access to the actual proprietary technical data used by companies such as AMSC and Motorola. Regardless, this paper attempts to address some of the issues that an actual system development would be forced to consider.

A significant portion of this paper is devoted to the definition of need. This is the first step in the system engineering process and is a critical facet of the systems
approach. Before large amounts of time and money are spent developing a system, it is extremely important that the identification of a current deficiency is well defined. If the deficiency is not clear, then the new system is probably not required and the entire process is stopped before monetary and human resources are wasted. If, however, a deficiency is evident, the process of defining the actual need should give those responsible for developing the system an excellent understanding of what need the system is supposed to fulfill. Additionally, the definition of need indicates the time frame in which the new system should become operational. In establishing the definition of need, considerable research is required to show beyond a shadow of a doubt that it is worth progressing with the system's development. Consequently, this portion of the analysis is a significant part of the entire paper.

The market analysis takes the definition of need a step further. While the definition of need identifies the need for the new system, the market analysis identifies the potential market for the new system. For example, most everyone would like to have a portable phone that allows them to call anywhere in the world, but if the cost of using such a phone is $20,000 a year, the market would probably be quite small. This analysis is done to ensure that enough people would purchase the product to make continued system
development worthwhile. If not, the process is stopped and resources are not wasted.

The feasibility analysis is where the system analysis becomes more technical. This analysis evaluates potential technical approaches that could be used to satisfy the identified need. This does not mean that different designs are discussed; the feasibility analysis is not that detailed. What it does do is present different system configurations that are available -- different black boxes, if you will. Those black boxes that are realistically incapable of meeting the need are eliminated from consideration before any further system development is attempted. Again, if the system that is being developed is not technically able to meet the need, then the system development can be stopped before any more time and money are invested.

Following the feasibility analysis, the operational requirements are established. The requirements stem predominantly from the definition of need and the feasibility analysis. In an actual systems analysis of a project of this scale, the operational requirements may be literally hundreds of pages long to ensure that each facet of the system will function effectively as part of the overall system. The operational requirements portion of this paper addresses the mission definition and some general
performance requirements. Since it is impossible to go into
detail on every requirement for the system in a paper of
this size, only a few selected topics are addressed in
somewhat more detail. Among these more detailed topics are
the international considerations and frequencies that are to
be used. These requirements are chosen because they
illustrate an interesting aspect of a global communications
system; namely, that to implement such a system requires
government cooperation on a worldwide scale. It consists of
much more than simply design and deployment -- there are
international regulations to be considered. By addressing
these topics, an aspect of the system that a technical
engineer working on the project would probably not even
consider is illustrated. Another set of requirements
covered in somewhat more detail are those for the handset.
Various aspects of the handset's function are considered and
from these observations, a series of requirements are
established. Other topics covered in more detail include
the operational deployment, and the marketing and
distribution of the system and its components.

After the operational requirements are established, a
section dedicated to system support is presented. This
section, the maintenance concept, is necessary to ensure
that aspects of the system not related to the system's
performance are addressed. One of the main functions of
systems engineering is to ensure that all aspects of the system are considered, including system maintenance throughout the life-cycle of the system. Failure to address these maintenance issues early on in the development of the system can be rather costly over the entire life of the system. In this paper, the maintenance concept -- especially as it pertains to the handunit -- is presented and issues such as levels of maintenance and logistics are addressed.

The next topic covered is the conceptual design. Like the feasibility analysis, this is a relatively technical aspect of the systems approach. In fact, the conceptual design is even more technical than the feasibility analysis. The conceptual design looks at different design alternatives for the black box chosen in the feasibility analysis. Of particular interest is the tradeoff analysis between two different types of satellite constellations. Quite a large portion of this section of the paper is dedicated to studying the tradeoffs. Based upon this study, one satellite configuration is chosen over the other. All the sections of the systems analysis prior to this section have an impact on which constellation is selected -- the choice is not made at the outset of the system development. This serves to illustrate the systems approach.
The final topic addressed is the detailed requirements. This section may appear to be out of place since an earlier section addressed the operational requirements; however, this section illustrates the feedback that is essential to the iterative systems approach. In an actual systems analysis, the information in the detailed requirements may be incorporated to the operational requirements. To do so in this paper would cloud the process of feedback from the conceptual design back to the operational requirements. The reason for the feedback is that at the conclusion of the operational requirements section, the type of satellite constellation has not been established so detailed requirements are somewhat irrelevant. At the end of the conceptual design section, the satellite constellation is selected. Thus, additional, more detailed requirements are established. Following this section, a brief functional flow diagram is presented.

Figure 5.2 summarizes the systems approach as it pertains to this paper.
Figure S2. The Systems Approach Used for the Global Communications System Using Portable Phones.
1.0 Definition of Need

1.1 Information Systems

The United States is in the midst of what many term the "Information Age". Additionally, some are going so far as to state that we are in an "Information Revolution." For instance, it is within the lifetime of many older Americans that the once miraculous phenomenon of a radio broadcast or an operator-free phone call has been relegated to the commonplace. Today, nearly every municipality in the U. S. offers cable television with its seventy-five or more channels, and the sight of a car phone no longer warrants a second glance. With these types of services, the United States has been inundated with information. Despite this volume of information, the desire for more has not abated.

This condition is not unique to the United States. With the ending of the Cold War and the economic/political programs such as Europe '92, countries are finding themselves in a "global economy". In order to be a player in this global economy, they must be able to interact with not only neighboring countries, but countries half-way around the world. With Western countries and Japan already leading the global marketplace, Eastern Bloc countries, Third World nations, and even the former Soviet Union are
being forced to compete without the infrastructure in which to do so. Not only is their infrastructure weak in terms of an industrial base and transportation systems, but their "information infrastructure" is also hopelessly behind. Essential business tools such as the telephone and fax machine are forced to use outdated telephone systems. Without this type of infrastructure, these countries' hopes of competing in the global marketplace are significantly inhibited. Thus, there is an urgent desire amongst these countries to develop informational systems that will facilitate information exchange internal -- and external -- to the country.

1.1.1 Methods To Exchange Information

There are many methods in which information is exchanged over long distances. Methods such as mail have been available for centuries, and recent improvements in delivery and sorting techniques have made mail even more efficient. Despite this efficiency, mail provides no better than a 48-hour turnaround in two-way communication. In an era where 48 hours can mean the difference between earning or losing large amounts of money (in the case of the world's stock exchanges which are no longer limited to those present on the exchanges' floors), the mail system -- no matter how
efficient it becomes -- will not ever provide the information exchange necessary to be a player in a global economy.

Real-time information exchange systems are becoming increasingly advanced. Mediums such as television and radio are available to more and more people throughout the world, and while they can supply information, they do not provide the user with any means to act upon the information received. With these mediums, communication is one-way. Thus, the user is also unable to immediately influence what information they receive. In terms of receiving the best information possible, the television and radio are limited because they do not allow instantaneous feedback by the user.

Two-way radios such as walkie-talkies provide real-time information as well as a means for the user to act upon the information. Additionally, because of the duplex (albeit half-duplex) communication capability, these radios allow the user to influence what information they receive by providing a means for immediate feedback. While this may appear to satisfy the information exchange hunger, radios are severely limited by distance. Consequently, they are unable to provide information over large distances which is the type of distances that information will be exchanged over in a global economy.
Telephones are capable of real-time, full-duplex information exchange. Thus, the user is able to act upon the data received as well as influence what data it is that they receive. These capabilities are essential to the most efficient exchange of information. Furthermore, other business tools such as modems and fax machines are able to use the same networks used by the phone. In the information age, the telephone is arguably the most valuable resource for the rapid exchange of information.

1.1.2 Telephone Limitations

The telephone is not without its share of drawbacks. For the most part, users are bound by the presence of a fixed, terrestrial, wire-based network. This is sufficient for many users, but not for those who may need telephone communications the most -- the many developing countries that are without reliable telephone networks. Without these networks, Third World nations are more or less isolated from the rest of the world when it comes to conducting day-to-day business. Consequently, the information that is essential to their participation in a world economy is absent. This condition only exacerbates their inability to join the West as influences on the global stage.
Users in the West are also stymied by the fixed telephone. Information exchange while driving and traveling is impossible with a fixed phone. Additionally, major economic efforts involving many people, such as off-shore oil fields or remote mining operations, are unable to communicate via conventional phone with their home bases. Furthermore, telephone communications with those in developing countries are hard to establish in many cases. This hinders the ability to penetrate the large, new markets that are becoming available as the global economy becomes more of a reality.

1.2 Cellular Phones

Despite its problems, the telephone is one information tool that has proved its value. The telephone has "made modern cities possible, ... created suburbs, made traveling salesmen obsolete, and gave birth to the home office phenomenon [Gutman, p.15]." In recent years, this revolutionary machine has itself been revolutionized with the introduction of the cellular phone.

In early 1984, the city of New York (pop. 7.2 million) was equipped to handle mobile phone users. Unfortunately, the system was limited to 800 users and only 12 calls could be made at any one time. In June of 1984, the city's
cellular system went on-line and was equipped to handle 100,000 users [Rock, p. 124]. Instead of mobile phone users being a member of an extremely elite club, the average person could join the "club" - if they could afford it.

1.2.1 Cellular Phone Costs

Since cellular phones have arrived on the scene, equipment costs have decreased as technology has improved. In 1984, the cost for equipment and installation of a cellular phone in a car, for example, was $2500. By the spring of 1985, this cost had decreased to approximately $1600 for installation and equipment [Rock, p. 124]. Prices have continued to drop: In 1990 cellular car phone prices fell to $200 [Kupfer, p. 143] and in 1991, cellular car phones could be purchased for under $100 [Gutman, p. 18].

Equipment costs were not the only costs to decrease. The average monthly bills for cellular phone customers have also decreased. In 1984, the average monthly bill was on the order of $300 [Rock, p. 124], but by the spring of 1989, this number had dropped to roughly $100 per month [Kupfer, p. 143]. In 1991, the average cellular phone bill had dropped even further to $83.94 per month [Gutman, p. 18].
1.2.2 Cellular Phone Demand

1.2.2.1 Cellular Phone Demand -- U.S.

As prices have decreased, the number of cellular phone subscribers has increased. In fact, some industry analysts describe the growth of cellular business as "blistering." In 1985 alone, the number of metropolitan areas with cellular service doubled from 30 in January to over 60 by the end of the year. In June of 1987, there were fewer than 800,000 subscribers. By June of 1988, there were more than 1.6 million subscribers [Slutsker, p. 138] -- more than a 100% increase in just one year. In 1990, statistics indicated that there were 4.4 million subscribers. Today, there are approximately 7.66 million cellular phone subscribers [CNN]. Furthermore, projections of up to 25 million cellular phone subscribers -- roughly one out of every four Americans over the age of 18 -- by 1999 are considered quite realistic [Kupfer, p. 143].

Figure 1.2.1-2 illustrates the drop in equipment cost, the drop in monthly bill charges, and the increase in demand for the United States.
Figure 1.2.1-2. Cellular Phone Equipment Costs, Monthly Bill Charges, and Number of Subscribers (US).
1.2.2.2 Cellular Phone Demand -- World

This dramatic increase in cellular phone subscribers is not unique to the United States. Developed countries such as Japan and those in Western Europe have experienced similar growth in subscriber numbers. Additionally, "there's a kind of cellular hysteria going on in the Third World [Kapstein, p. 80]." In these developing countries, there is greater acceptance that new phone systems speed economic development [Kapstein, p. 80]. Instead of investing the money -- and perhaps the more valuable commodity of time -- in a new ground telecommunications system, some countries see the immediate installation of a cellular system as the quickest manner to improve their country's "information infrastructure." As one industry analyst states:

In less developed nations, the new wireless phone systems are a rapid and low-cost alternative to upgrading crumbling local telephone networks. Cellular phones are not a permanent substitute for reliable land lines, but they are the fastest way to get good phone service... [Kapstein, p. 81].
Not only are some governments of Third World nations encouraging the establishment of cellular telephone services, but businesses within the countries are supporting cellular systems. For example, in Bombay and New Delhi in India, local telecommunications systems are so unreliable that businesses employ full-time workers just to place calls across town. In fact, conditions are so bad that a number of businesses in these cities have offered to pay for the installation of a cellular phone system out of their own pockets. (In this case, the offer has been refused by the Secretary of Telecommunications in India because cellular phones were considered to be "toys for the rich".) In Argentina and Venezuela, businesses are using cellular networks to get around unreliable land lines. Furthermore, there was a 1200 person waiting list for new cellular phone numbers in Indonesia in 1990. The country's poor telecommunications system is credited for this high interest [Kapstein, p. 81].

Businesses based in the developing countries are not the only ones interested in developing cellular systems. Many foreign corporations that have attempted to set up businesses in these countries have become so frustrated with the poor local telephone systems that they have financed the cost of a cellular phone system in their locality. This was
done by a Japanese company in Thailand with very successful results [Kapstein, p. 81].

In summary, the worldwide demand for cellular phones is increasing, especially among Third World nations. Motorola, a leading company in mobile telephone technology, predicts that in the year 2001, there will be over 100 million subscribers to cellular phone systems.

1.2.3 Cellular Phone Problems

A cellular telephone system divides the area that the system serves into different segments called cells. As a person moves from cell-to-cell within a cellular network, a computer "hands off" the user to a new cell. By shrinking the distance the phones need to transmit, this type of configuration allows users to avoid the fade and static that was common among previous mobile phone systems. However, it also causes other problems [Kupfer, p. 143].

1.2.3.1 Cellular Phone Problems -- Network Design

One problem is the cell boundary. As a person travels along the boundary between two cells, it is possible that the computer will continually "hand off" the user between the two cells. This can render conversation almost impossible
"Cellular Radio," p. 108]. Additionally, if many people are on a boundary at one time, the multiple switching performed by the computer could exceed the computer's switching capability. This could result in a computer malfunction which quite possibly would render a large portion -- if not all -- of the network inoperable ["Cellular Radio, p. 108].

Another problem is that not all cellular phone networks are uniform. That is, cellular phones that work in one city may not necessarily work in another city [Rock, p. 126]. This is obviously a major inconvenience for the cellular phone owner. For example, a salesperson whose territory includes, say, three different metropolitan areas could be forced to purchase three different phones. This lack of uniformity in cellular phone networks also causes a problem for phone calls that cross cellular network boundaries. For instance, the subscriber's home network may not be able to forward calls to another system. Other networks require that the caller know where the person receiving the call is located, and then require the caller to dial a cumbersome code to access the receiver of the call's home network [Kupfer, p. 143]. Not only does this make communication difficult, but also impossible if the caller does not know where the person they are calling is. Furthermore, system
operators hit users with large extra charges for inter-network calls.

1.2.3.2 Cellular Phone Problems -- Increased Demand

While the computer systems that handle cellular networks are improving, and measures to make cellular networks more uniform have been taken, these problems still persist. But neither of these problems are the most severe to affect the cellular phone industry. "The big problem now ... and in the future will be adding subscribers to jammed cellular systems [Slutsker, p. 138]."

As the number of subscribers to a particular cellular system increases, the systems can accommodate the newcomers in one of two ways: receive new frequency allocations from the FCC, or decrease the size of the cells [Slutsker, p. 138]. The former solution has proven to be difficult with the increasingly strict practices of the FCC, and thus the second solution has been chosen by default. This solution is far from ideal. As the size of the cells decreases, the amount of interference increases. Consider that in both New York and Tokyo, only 80% of the calls are successful during peak times [Kupfer, p. 143]. Additionally, the smaller the cells, the larger the number of cell boundaries, and the larger the number of "hand offs" the network's computers
need to make. Thus, the computers are further burdened, and with every switch from cell to cell, the probability of a call being lost increases. These new cells are also expensive. At the end of 1990, the cost of a new cell was approximately $500,000 [Rock, p. 126]. Finally, there is also a limit to how small the cells can be. In Los Angeles -- a city where the cellular traffic is nearly as heavy as the freeway traffic -- some cells have been reduced to just 30 feet by 60 feet [Slutsker, p. 138]. Despite the fact that most cellular systems have been around for less than a decade, they are already approaching the limitations to the number of subscribers that they can handle.

1.2.3.3 Cellular Phone Problems -- Mobility

Cellular phone systems are an improvement over the traditional wire-based phone networks because of the mobility they offer the user. While this mobility is impeded by such issues as boundary "hand offs" described previously, the most important facet of the cellular systems that effect mobility is the actual phone.

Nearly all of the cellular phones currently in use are dependent upon the power supplied by a car battery. This prevents the cellular phone from being truly mobile; it is only as mobile as the car. Many of the phones that are not
physically attached to a car require the operator to carry a cumbersome power-pack that inhibits the mobility of the phone. These factors prevent cellular phone systems from providing the convenience needed for mobile, personal communications to flourish.

1.3 Definition of Need -- Conclusion

As stated previously, given the political situation in the world now and economic situation in the future, there is an increasing desire for information. This interest encompasses both industrialized nations as well as developing nations. Although there are many ways that information can be exchanged, the telephone and, more specifically, the cellular phone are among the most popular and efficient means of providing communications.

While offering considerable improvement over previous mobile phone systems, current cellular phone systems are not without their share of problems. Network designs have had their share of flaws, and the lack of uniform network design has been particularly troubling. Despite these problems, in less than a decade, prices have dropped significantly. With this drop, demand has escalated to the point where many cellular systems are approaching the limits to their capacity.
There is a need for a new mobile phone system. In order to be truly mobile, this system must function using phones that are portable. This system must satisfy the needs of the metropolitan Los Angeles resident as well as the isolated village in the Africa. In other words, it must function in a worldwide environment rather than a local -- or even national -- environment. With the rapid changes occurring today, such a world-wide phone system should be operational by the year 2000. Without such a system, developing nations will be pushed further and further off of the global economic stage, and current cellular phone systems in industrialized nations will continue to experience problems with the increasing number of cellular phone subscribers and the inconveniences of non-portable phone units. These problems will inhibit the economic growth and exchange of information for countries throughout the world. This new system, the Global Communications System Using Portable Phones, or GCSUPP (pronounced GICKS-up) should alleviate these problems.
2.0 Market Analysis

2.1 Demand

Section 1.0 of this paper has illustrated the need for a mobile phone system that will function on a worldwide scale. Additionally, section 1.2.2 (Cellular Phone Demand) has established -- in part -- the demand for such a service. However, the actual demographics of the phone users needs to be considered.

2.1.1 Urban Demand

Although the current cellular phone systems located in urban areas are rapidly becoming overburdened, there is no sign of decreasing demand. This market is established and shows no sign of decreasing. Nevertheless, there is evidence that a significant demand exists amongst mobile users whose needs are not met by current terrestrial systems. Enhancements that do not significantly increase cost to the current systems should only increase the current demand, but the percentage increase in new subscribers will probably not be as significant as in the other "untapped" areas. It is these other areas that have not used cellular
phones in the past where the potential market is more unknown.

2.1.2 Rural Demand

In general, people living in rural areas have not used mobile telephones as much as those living in urban areas. The reason, simply, is that cellular telephone networks have not been established in those areas that are sparsely populated. Traditional cellular systems cost too much to install in large areas since the larger the area, the more cells that are required, and, hence, increased cost. Although this cost could be passed on to the subscriber, these charges would be prohibitive since there is a price sensitivity among mobile phone users. This sensitivity is explored in section 2.2.

Regardless of how much impact the total cost of owning a cellular phone has on demand, there remains a need for mobile telecommunications in a rural environment (reference section 1.2.2.2 (Cellular Phone Demand -- World)). If there is a need, there is at least a potential market. A Canadian study conducted in the mid-1980's indicated that organizations involved with traditionally rural activities such as transportation, mining, forestry, and some government operations were extremely receptive to the
proposal of a mobile phone system that would function in a rural environment. Some of the applications of a rural mobile phone system that interested these parties include

- forest fire fighting communication
- remote area medical emergency response
- communication to/from remote construction sites
- data transmission to/from remote oil well sites
- communications to inter-city passenger vehicles (i.e., buses, trains, etc.)
- inter-city trucking
- law enforcement voice and data communications

[Sward, p. 181]. These applications are not unique to Canada and could be applied to virtually any country in the world that has a significant rural population. It is this market that has not been penetrated that provides a large potential increase in subscribers to a mobile telecommunications system.

2.1.3 Undeveloped Countries' Demand

Undeveloped countries also provide a market that has not been tapped by current mobile phone systems. As stated in section 1.2.2.2 (Cellular Phone Demand -- World), many developing countries consider a mobile phone system the quickest way to get good phone service. If this phone
service is also able to provide communications worldwide, the developing countries will accelerate their assimilation into the increasingly global economy. Since many Third World countries express their desire in joining the global marketplace, there is definitely a potential market. Also, although the populace of these countries are notoriously poor, the sheer numbers of people in these areas make the potential market, in a word, enormous. Although it may seem irrelevant to consider a financially disadvantaged populace a potential market, there are still possibilities. For instance, a village or neighborhood could pool their resources and purchase one phone for many people. Similarly, a government organization could purchase a phone for a remote village and save themselves many dollars in transportation costs. Again, the large numbers of people involved indicates a large potential market.

Consider that in 1990, 77% of the world's population lived in countries that are considered undeveloped. By the year 2000, this number is projected to increase to approximately 80%. If projections that 1-in-4 Americans over age 18 will be subscribing to mobile phone systems (assuming no major changes in the mobile phone systems offered) by the year 2000 are accurate, then there will be roughly 25 million subscribers in the U.S. If just 1-in-40 people over 18 subscribe in the rest of the world, the rest
of the world will contribute over 100 million subscribers. This is illustrated in Figure 2.1.3.1. Thus, the developing countries represent a tremendous potential market even if their proportion of subscribers is only 10% of that of the U.S.. In summary, as long as Third World nations continue to want to develop, there will be an immense potential market.
* = Assumes 1-in-4 people over age 18 subscribe
+ = Assumes 1-in-40 people over age 18 subscribe

Figure 2.1.3.1. Potential Market for Mobile Phone Subscribers by the Year 2000.
2.2 Price Sensitivity

There are basically three components of cost to the user associated with a mobile telecommunications service: the user's hardware cost, the monthly access charge, and the airtime usage fee. Of these components, the Canadian study cited earlier determined that users were most sensitive to increases to airtime usage fees, but this sensitivity was low [Sward, p. 181]. The general insensitivity of the Canadian survey's respondents to price is indicative of the strong need for a mobile communications service that features better coverage, extended range, and higher reliability than the current systems.

Using more current data -- the Canadian study was done in the mid-1980's -- there is evidence of price sensitivity of a different sort. This sensitivity shows a large increase in demand as prices decrease. This type of price sensitivity is supported by the data presented in section 1.2.1 (Cellular Phone Costs) and section 1.2.2.1 (Cellular Phone Demand -- U. S.) and by Figure 1.2.1-2. Although one can not conclude that price alone is the reason for the increased number of cellular phone subscribers, there is undoubtedly a connection. This connection may prove to be most apparent in the Third World market where the populace and nations are extremely poor. Additionally, the
predominant reason for the lower cost in mobile communications equipment is due to improved technology. Currently, the advances in technology show no signs of abating. Thus, as technological improvements continue to be made, prices will continue to drop, and demand will continue to increase, thereby increasing the market for a mobile telecommunications system.

[NOTE: In order to truly quantify what type of market is being discussed, additional work would be required. For instance, extensive surveys among large, medium, and small city dwellers -- both those that currently subscribe to a cellular system and those that do not -- should be conducted. Additionally, people that reside in rural environments should be contacted as well as citizens and governments of developing countries. Issues such as price and system usage time should be included in the survey to help gauge the demand based upon price sensitivity.

Once this data is collected, economic evaluation tools should be applied to establish what the correlation is between cost and demand among the various potential users. Since the relationship is not likely to be the same, say, for a suburban resident in the United States as for a rural government worker in India, an analysis is needed to determine what price (or prices) will maximize profits.
From this analysis, system requirements such as the cost of the handunit can be established in a much more logical and realistic manner than if the decision is left to a group of engineers working together in one location.]

2.3 Conclusion

The number of subscribers for mobile telecommunications has been increasing significantly in recent years and this trend shows few signs of changing. For the most part, these subscribers have been limited to urban dwellers where cellular phone systems have been established. Enhancements to the current system in the form of improved quality and additional capabilities that do not significantly increase price will only increase the market for mobile phone systems in urban areas. This is an established and reliable market. A new system that also attracts rural users has the potential to greatly increase the number of subscribers since the rural market has not previously been tapped. The new system also has a large potential market amongst developing nations. It is the rural market and the Third World market that the new system must accommodate at relatively low cost if it is to truly provide worldwide mobile telephone capabilities. Given the past demand and success of mobile phone systems and the established and
potential markets for an enhanced mobile system, the earning potential and financial success of GCSUPP is considered to be excellent.
3.0 Feasibility Analysis

The Definition of Need presented in section 1.0 concluded that there is currently a need for a system that would provide global communications using portable phones. The Market Analysis in section 2.0 indicates that such a venture has a solid market and would be financially worthwhile. In order to develop such a system, there are essentially three choices: enhance local telephone networks, enhance current cellular phone networks, or establish a satellite-based system.

3.1 Local Telephone Networks

One method of providing worldwide telephone communications is to establish local telephone networks throughout the world. This is difficult since the responsibility and funding needed to establish such networks is the responsibility of a country's government. It is not feasible to have a private company implement these networks at every location on the globe. Additionally, the Definition of Need identified that the problem of poor telephone communications in many developing countries is most readily and inexpensively solved by a cellular phone system. A fixed telephone system would take too long to
establish. Although a local telephone network could aid in the establishment of a cellular phone system (i.e., the cellular phone user in the U.S. could be routed to a fixed phone where a local network is established), a local telephone network in itself does not provide the mobile telephone service desired. Thus, attempting to establish local telephone networks throughout the world is not feasible and would not satisfy the identified need.

3.2 Current Cellular Phone Networks

The use of the current cellular phone network implementation method could satisfy both the need for a worldwide telephone communication system and the need for a portable telephone communication system. However, the feasibility of establishing a cellular phone system in the vast, uninhabited regions of the world would be prohibitive. For instance, a cellular phone system using the current implementation scheme would require numerous cells to reach a research lab in the Anatarctica. With the cost of a cell being roughly $500,000 (reference section 1.2.3.2 (Cellular Phone Problems -- Increased Demand)), establishing thousands of cells to reach only a few people is not practical. It is this high cost that has prevented rural areas from receiving cellular phone systems in recent years (reference section
2.1.2 (Rural Demand)). Additionally, the construction of the relay towers within the cells might not be possible in certain areas, such as the Himalaya Mountains. If relay towers could be constructed at such locations, maintenance and replacement costs would certainly be prohibitive.

A further consideration is the technological advances in communication systems that are certain to occur. The last two decades have witnessed major improvements in mobile phone system components and there is little reason to suspect that the next two decades will see any fewer advances. With these improvements, equipment should be upgraded to take advantage of the new technology. A worldwide mobile phone system using the current cellular phone network configuration would consist of so many cells that upgrading the equipment in each cell would be an expensive, time-intensive, and generally massive undertaking. This would probably make network-wide upgrades impossible and could potentially render the worldwide network obsolete in a very short time.

Not only do the sparsely populated areas and the geographically extreme areas of the world make establishing a worldwide mobile phone system using the current cellular phone implementation scheme impractical, but the highly populated areas of the world also cause problems. It has already been shown that the current cellular phone systems
experience problems as the number of subscribers "saturate" a system. If a worldwide system was implemented using the current scheme, the current problems would persist and spread as the number of users increase. This is unacceptable.

Because of geographical problems, the inability to assimilate technological advancements into the network, and the problems with population distribution, this option is not feasible.

3.3 Satellite System

The use of a satellite system would satisfy the need to provide mobile telephone communications on a global basis. Ever since the INTELSAT I (Early Bird) satellite was brought on station over the Atlantic on April 6th, 1965, satellites have been used to carry phone calls across oceans and continents [Bleazard, p. 47]. Thus, the use of satellites for telephone communications is proven.

Not only have satellites proven useful for relaying intercontinental telephone calls between two fixed phones, but they have also shown their capabilities in mobile communications. The INMARSAT system which provides ship-to-ship and ship-to-shore telephone communications via satellite became operational in 1982 [Binkowski, p. 82].
This system has been very successful in establishing communication links between mobile users.

Satellites have been shown to be capable of providing telephone communications, and especially mobile telephone communications, to users throughout the world. The INTELSAT satellites have been used extensively in relaying intercontinental telephone calls and the INMARSAT system has provided mobile communications via satellite. The technology required to operate these systems is over a decade old and since their development, numerous advances in the fields of satellites and communications have been achieved. Given the past performance of satellite-based communication systems and the present technology, it is feasible to establish a worldwide mobile phone system using satellites.
4.0 Operational Requirements

4.1 Mission Definition

The broad goal of the new satellite-based communications system is to provide affordable, mobile, personal communication on a totally global basis. More specifically, the system should take advantage of the latest technology to provide primarily commercial, rural, and mobile communication service to any user in the world whether they be on land, sea, or air. This service should include both voice and the data communications that are capable with conventional phones and phone lines. The system must provide these services, but remain free from costly, burdensome "suitcase-type phones" which are ineffective in spurring mobile communications usage.

4.2 General Performance Requirements

4.2.1 General Performance Reqs -- Rural Areas

Unlike the terrestrial cellular telephone system, the new satellite system should be best suited for areas where the traffic density is low such as sparsely populated areas and even the ocean. In the rural areas where the market is
just emerging, the satellite system should serve as a primer for an eventual land-based system; that is, it should bridge the gap between no telephone service and a permanent, fixed network. It will provide immediate telephone communication capability.

4.2.2 General Performance Reqs -- Communication Units

To implement this new system, the devices used to communicate must be relatively small and light since a large, heavy device may prevent the use of the communication unit (i.e., phone) during certain routine activities such as going to the store or operating farm equipment. Essentially, the phones must be portable and pocket-sized, and, therefore, must be able to function with relatively low power. Additionally, the antennas must not be cumbersome to the user.

4.2.3 General Performance Reqs -- Current System Interface

Not only should the new satellite-based communications system provide global personal communication, but it should do so as a complement, not in competition with, current terrestrial cellular systems, wired systems, and even other mobile systems such as INMARSAT. It must not function as a
bypass system, and the phone used for the satellite-based system must also be compatible with the local terrestrial cellular phone service. To be compatible and still provide worldwide capabilities, the new system's handset should be able to communicate with the satellites overhead as well as with the public telephone networks. To use the local phone systems, the new system should first search for and use terrestrial channels and open a satellite circuit only if a local cellular radio circuit is unavailable.

This will help ensure least cost routing, will maximize its utility for the user, and will allow for new network alternatives by using a combination of terrestrial and satellite personal communication systems. More importantly, this compatible configuration will make the various national authorities whose job it is to ensure their nation's interests are protected more acceptable to the presence of this system.

4.2.4 General Performance Regts -- Usage

The worldwide satellite based mobile communications system should be operational 24 hours per day, 365 days per year. It should function in literally every climate of the world from the tropical rain forest, to the tundra, to the ocean, to the desert. It should also be able to function in
all ranges of temperatures found on the earth. Anything less would not be an actual worldwide system.

4.2.5 General Performance Reqs -- Locating Users

Unlike some of the current cellular systems, the new mobile communications system should be able to connect any callers throughout the world without either of the callers knowing the location of the other user. That is, when a person places a call, the system will locate the phone of the person receiving the call. This will allow totally global communications.

4.2.6 General Performance Reqs -- Humanitarian Uses

Outside of the profit making aspect of the project, the new system should be capable of providing worldwide support for relief and rescue efforts following a disaster or emergency. International relief agencies should be solicited for assistance in developing the disaster assistance aspects of this system.
4.2.7 General Performance Reqs -- Summary

In summary, the new satellite-based system must provide a mobile communications system such that pocket-sized, light-weight, low power phones can send and receive calls and data anywhere at any time. The system must handle users on land, sea, and air as well as those in both developed and undeveloped areas. It must perform these functions within the framework of current telecommunication systems, and the system must be able to provide communications to areas stricken by disasters.

4.3 International Considerations

If the new portable telecommunications system is to function worldwide, then all nations and governments of the world must be agreeable to certain basic characteristics of the system. For instance, if the new system is to function as a part of the country's public networks, the system will be subjected to the rules of the country, such as regulating call authorization and tariffing. Thus, it is a requirement that international agreement to some aspects of the system be established before the actual design of the system and its components is attempted.
4.3.1 Initial Considerations -- Frequency Allocation

Perhaps the most important consideration is the securing of frequencies for the worldwide system. Agreement on spectrum allocation is critical to having the same units function anywhere in the world. That is, having one country allocate one frequency for the portable phones and having another country allocate another frequency would only serve to make the new system contain one of the least desirable features of some of the current cellular systems: the inability to use one phone everywhere. Also, the frequencies that are secured will dictate the design and hardware for the various system components.

In order to secure the necessary spectrum allocations, the GCSUPP system must involve the International Telecommunications Union (ITU). This organization is the United Nations regulatory and standards-setting body and is located in Geneva, Switzerland. It is imperative that this organization be involved in the selection of the frequencies and their approval obtained. The interface between the system administrators and the ITU will be via the Federal Communications Commission (FCC) since the FCC submits frequency requests to the International Frequency Registration Board (IFRB) on behalf of United States corporations. The ITU regulations require that any country
intending to launch as new satellite system to submit frequency information about the system to the IFRB. The IFRB then will coordinate frequency use and resolve possible interference issues.

[NOTE: In February of 1992, the ITU held its first broad allocation conference since 1979 in Torremolinos, Spain to consider primarily the frequency allocations in the 1 GHz to 3 GHz range; the frequencies used for many mobile communications systems. This World Administrative Radio Conference, known as WARC-92, met for one month and decided to grant the necessary frequency allocations for a space-based worldwide mobile telecommunications system. This decision carries a treaty status and must be approved and ratified by member governments.

In getting the allocation approved, the U.S., with help from many developing countries, prevailed against opposition from Europe. Europe's opposition stemmed from a reluctance to reassign spectrum space for their current cellular systems which, unlike most areas of the world, already provide coverage over most of their continent.]
4.4 Frequency Selection

Since it is essential that the new system function within the framework of the current cellular systems, the frequencies selected should range from roughly 1 GHz to 2 GHz. However, use of these frequencies is contingent upon approval of the ITU. These frequencies are in the Ultra High Frequency (UHF) range and also in the L and S band range. Characteristics of these frequencies include line-of-sight propagation and freedom from rainfall attenuation (which occurs at frequencies over 10 GHz). These are desirable qualities because they foster the ability to relay data between transmission towers and they allow the system to function in the rain -- although rain does affect other portions of the system, such as the antenna and its associated noise temperature. Additionally, these frequencies are relatively low and generally, the lower the frequency, the simpler and less expensive the required hardware.

The selection of the frequencies will be impacted by considerations of other users of the frequencies. Currently, many satellite communications systems share frequency allocations with terrestrial communications systems. Coordination of frequencies should be studied to ensure that the system will not interfere with other
systems. Consideration must also be given to other mobile systems such as maritime mobile systems, such as INMARSAT, which use frequencies between 1.53 GHz to 1.64 GHz and aeronautical mobile systems which use those between 1.54 GHz to 1.66 GHz.

Selection of the frequencies should be done so as to minimize the impact on other users that may have to be relocated. To do this, the spectrum of roughly 1.610 GHz to 1.6265 GHz is suggested since this band is relatively unused around the world at this time. Again, this operating range is contingent upon ITU approval. The range of 1 GHz to 2 GHz and, more specifically, 1.610-1.6265 GHz, should be used for the frequency requirement.

4.5 Communication Unit Requirements

The general performance requirements of the communication units are addressed in section 4.2.2 (General Performance Requirements -- Communication Units). More specific requirements include the units' size, weight, features and cost.
4.5.1 Communication Unit Rests -- Size

Each unit should be no larger than nine inches-by-three inches-by-one inch -- roughly the size of a thick checkbook. The unit should also weigh no more than 25 ounces. These requirements are depicted in Figure 4.5.1. This size and weight will allow the phone to be carried easily in a purse, backpack, or even a pocket. This will allow the unit to meet the need for a mobile phone system that is truly portable.

[NOTE: These requirements are not merely wishful thinking. Mitsubishi's Model 3000, which has been on the market for over a year as of this writing, weighs just 10 ounces and is roughly the size of the aforementioned checkbook. However, this unit does not communicate directly with satellites.]
Net Weight = 25 oz.

Figure 4.5.1. Communications Unit Size Requirements
4.5.2 Communication Unit Reqs - Handling Considerations

The unit should be able to stand up on its base (the bottom of the unit) or on its side on a level surface with no outside supports. The outside of the unit shall be made and/or covered with a lightweight cushioning material to protect the unit from falls. This material must be sufficiently shock-absorbant to withstand falls from 6 feet onto concrete or any other hard surface without suffering any damage to the outside of the case. Internally, the supporting electronics must also be able to withstand jolts caused by a 6 foot fall. This requirement includes falls onto any side or corner of the communication unit.

If the unit is in a purse or backpack, it is conceivable that an unwanted phone number could be dialed because of jostling. To prevent this from happening, the communication unit shall provide a "lockout" feature on the keypad to prevent such unwanted calls. This lockout feature will prevent any outgoing calls from being made unless the user first enters a four-digit PIN such as those used for ATM transactions. (The unit will still be able to handle incoming calls without the user entering the PIN.) In order to place an outgoing call, the user must first enter their four-digit PIN, then the desired number. Without the PIN prefix, the outgoing call will not be made.
4.5.3 Communication Unit Regts -- Data Ports

Not only must the handset be small enough to be truly portable, but it should be equipped with data ports to allow the transmission of faxes and computer files. This is an essential requirement in order to meet the growing demand for mobile data transmission. These ports shall be located on the back of the communication unit.

4.5.4 Communication Unit Regts -- Cost

As stated before, this new system should provide worldwide communication. That is, a person in Chicago should be able to call a person in a hut in Botswana. If this is to occur, the cost of the phones must be such that the system is not a toy for the rich and is available to everyone. The unit should cost less than $3,000 for a communication unit that provides every feature (i.e., voice, modem, and fax capability). While this may seem to be a large cost, consider that such a unit must be pocket-sized, compatible with faxes and computers, able to function in current cellular phone systems, detect whether it is possible to use a terrestrial system or whether it should use the satellite as a transmission channel, and must be
able to transmit to a satellite. While cheaper units may be possible, they would not fulfill all of the requirements (i.e., they would be too large, they would be unable to interface with current systems, etc.). It is fully expected that this cost will drop as technology improves.

To keep communication units' costs low, a scaled down communication unit should be provided. This unit would provide only voice telephone capability and not any modem or fax interface capability. This unit should not cost any more than $2,200. This communication unit will provide the basic global service to most users, while eliminating features that some users would not need anyway at this time. Other than the data port feature, the other communication unit requirements all apply.

4.5.5 Communication Unit Regts -- User Notification

The communication unit should provide two different methods of notifying the user that an incoming call is being received. These methods are a series of beeps or visual indication in the form of a light. These notification methods can be activated concurrently or separately, and the control of which indicator or indicators are activated is at the discretion of the user. The selection will be via a switch on the side of the unit. This switch shall be in
the form of a sliding mechanism and should be nearly flush with the unit.

The audible notification shall emanate from a speaker at the top of the communication unit. This location will prevent the audible notification from being muffled while the unit is standing up or placed on its side (it will not be capable of standing on its own upside down). The audible alarm shall also be controlled by a switch on the unit. This audible alarm switch shall have a low and high setting where low and high refer to the volume of the speaker. This will allow the user to be notified at a distance from the unit, or to be notified quietly in the event the user is near the unit or in a situation where they do not want to disturb others, such as a meeting. The high volume setting shall be louder than 35 decibels but not louder than 45 decibels at a distance of 10 feet from the unit. The low volume setting shall be louder than 10 decibels but not louder than 15 decibels at a distance of 5 feet. The sound shall carry almost equally -- within 4 decibels in the case of the loud volume and within 2 decibels in the case of the soft volume -- in all directions except below the communication unit. The speakers shall operate with a MTBF of 1200 hours (approximately 10 years with an average use of 20 minutes per day).
The visual notification method shall use a small, low-
power green light located at the top of the communication
unit. This light should not be flush with the top of the unit so that it can be seen in all directions. Since it is not flush with the top of the unit, the light must be able to withstand a fall of 6 feet onto a hard surface without cracking or breaking once it is installed on the unit. When a call is received the green light should flash at a 2 Hz rate until the caller hangs up or the person receiving the call answers the phone. When the phone is answered, the light should stop flashing. The light should have a MTBF of 600 hours (approximately 5 years with an average use of 20 minutes per day).

4.5.6 Communication Unit Regts -- Keypad

The keypad for the communication unit shall mirror the keypad of a conventional phone. The keypad should also be capable of being illuminated so that the phone can be used in the dark. Because having the keypad constantly lighted would place an unnecessary burden on the unit's battery (and battery life is of very important in this type of device), the user shall control whether or not the keypad light is on via a slide-switch on the side of the unit. The keypad
lighting shall have a MTBF of 14,500 hours (approximately 5 years with an average use of 8 hours per day).

4.5.7 Communication Unit Reqs -- Answering the Phone

Since the communication unit will not rest in a cradle of some sort like a conventional phone, the unit must have a means of "answering" the phone or preparing to place a call. To perform these functions, the communication unit should have a button placed below the keypad. This button will serve as a toggling switch: if a call comes in and the button is pushed, the call is answered. At the conclusion of the call, the button is pushed again and the user "hangs up" the unit. Similarly, the button must be pushed prior to the user initiating a call.

4.5.8 Communication Unit Reqs -- Human Factors

In order to operate the communication unit, the user shall need no additional skills, training, or education level than those needed to operate a conventional phone. The unit shall not heat up beyond 110 degrees farhenheit during operation so the user need not be concerned with any discomfort when handling the device. The user should not
have to talk any louder than they currently do on a fixed phone.

4.6 Operational Deployment

As identified in the definition of need, the new system should be operational by the year 2000. In order to meet this deadline, various vendors with expertise in specific fields should be included in the development of the system. In order to get the best possible product, detailed requirements will be established and made available to various vendors.

In the case of the major system components such as the satellites and their ground stations, the vendors are required to submit proposals that meet the requirements. From these proposals, the vendors will be selected and awarded exclusive contracts to develop their specific components. This approach will ensure the best design of the high-cost components is selected and that they are strictly monitored for quality. If these components of the system are not effective, the system will not be a success.

In the case of the smaller -- but still critical -- components such as the handheld unit, the requirements will be made available to manufacturing vendors. All interested vendors are then free to produce the units as long as the
products meet all requirements including physical requirements and reliability requirements. A portion of the revenue generated from each unit sold will be forwarded by the manufacturing company to the "host" system company (the "host" company is the company responsible for the overall GCSUPP system). If a vendor cannot produce a quality product, they will no longer be given permission to produce the unit. This method of handset production will help spur competition amongst the handset producers and drive down costs. As costs are reduced, the number of users will increase, and the system will advance closer to its goal of providing worldwide communication service for all people.

4.7 Marketing and Distribution

As for marketing and the distribution of components such as the phone unit, this will be done predominantly on the local level by current cellular phone companies. As stated previously, the new system should serve as an enhancement and not as a competitor to current systems. Thus, existing terrestrial cellular operators should be strongly motivated to market the new worldwide satellite-based mobile phone system to their cellular customers as an integral part of their existing services. Since these
current cellular companies already have marketing departments in place (and judging by the increase in cellular customers over the years, effective ones at that), they should be used. This will eliminate the cost of setting up large-scale marketing campaigns and the cost of establishing a retail distribution system. In fact, there will be very little in the way of direct customer interaction; the customer's interface with the network is via the handset and these handsets will be built by various contractors and sold by established cellular companies. The host company is mainly responsible for the technical aspects of getting the satellite system working and interfacing with current cellular systems.
5.0 Reliability and Maintenance

There are three major components to consider in the system and the reliability requirements and maintenance requirements are different for each component. These components are the handset, the satellite ground stations, and the satellites.

5.1 Reliability and Maintenance -- Handset

5.1.1 General Reliability

The reliability and maintenance requirements are the least strict for the handset component. This does not mean that poor performance will in any way be tolerated. The companies that produce the handset must ensure that the handsets have a minimum life expectancy of 6 years with an average of 2 hours of use per day, and 4 years with an average use of 6 hours per day. The handset should be rated with a mean time between failures of 2,000 hours. The handsets need not be designed to last longer than 6 years since recent advances in portable phone technology show no signs of abating and it is expected that the first generation of phones will be obsolete within the first 10
years. These requirements may become more strict as the potential for advances in portable phone design decrease.

5.1.2 Handset Maintenance

The maintenance of the handsets will consist of organizational maintenance, intermediate maintenance, and producer maintenance. Together, these maintenance levels will ensure the proper support for the handsets throughout the system's life-cycle.

5.1.2.1 Organizational Maintenance

Organizational maintenance is maintenance that is performed by the consumer, namely the user of the handset. For the GCSUPP system, the user will be responsible for replacing the battery that is used to power the handunit. Hence, the skills required to replace the battery are extremely low and should not require any special equipment or location. The battery for the unit will need to be replaced when the unit ceases to function as it should. If the unit still does not function correctly after the battery is replaced, additional maintenance in the form of intermediate maintenance may be required.
5.1.2.2 Intermediate Maintenance

Intermediate maintenance is maintenance that supports the organizational maintenance. In this case, the intermediate maintenance should be performed at an establishment that sells the handsets. The maintenance performed at these locations requires some skill and training which will be provided by manuals sent to each establishment that markets the units. Maintenance will be only in the form of replacement and not repair, and the failed components should be sent to the producer maintenance facility. For instance, the speakers used for talking and listening as well as the speaker for in-coming call notification should be replaced and not repaired. Then, the faulty speakers should be sent to the producer maintenance location. Internal circuit boards can also be replaced at this level, although individual components on the circuit boards should not be. The maintenance should be performed within 24 hours. During the 24 hours that the unit is being repaired, the user shall be provided a temporary replacement unit programmed with the same phone number as they had previously. If the original unit can not be returned to operation within 24 hours, the faulty unit and any faulty components should then be sent to the producer maintenance level via express mail. By having all replaced parts sent
to these producer maintenance locations, the recurring problems with the handsets can be more easily tracked and monitored.

5.1.2.3 Producer Maintenance

The maintenance performed by the producer is to repair the units that the intermediate maintenance could not return to an operating condition. Because this system is to be implemented worldwide, the producer maintenance locations shall consist of one location on each continent except for Antarctica. The maintenance skill level at these locations needs to be high for the personnel tasked with repairing the units, and an intermediate skill level is required for testing activities and taking apart units. The highly skilled maintenance personnel should be familiar with the handunit design. Once a unit arrives at the producer maintenance location, it shall be tested on in-house test equipment. This equipment should identify which portion of the handset failed. The maintenance personnel should then fix the problem and mail the repaired unit back to the intermediate maintenance location via express mail. The total time from the receipt of the faulty unit at the producer maintenance facility until the mailing of the repaired unit to the intermediate maintenance location shall
be not longer than 7 days. The user shall then return the temporary replacement unit and receive the repaired unit. If the handset can not be repaired within 7 days at the producer location and the unit is under 2 years old, the user shall be provided with a new unit. If the unit is over 2 years old, the unit shall be taken apart, its components tested, and the functioning components sent to the intermediate maintenance locations to serve as replacement components. The user will then be required to return the temporary unit and purchase another unit.

An abbreviated maintenance functional flow diagram is presented in Figure 5.1.2.
Figure 5.1.2. Maintenance Functional Flow Diagram.
Figure 5.1.2. Maintenance Functional Flow Diagram (cont.).
5.1.3 Logistic Considerations

Each intermediate location shall carry replacement batteries for the user to purchase so they can perform the necessary organizational maintenance. Additionally, the intermediate maintenance locations shall maintain sufficient inventory of various handset components such that the availability of replacement components is not the reason that maintenance is not performed within 24 hours. Finally, the intermediate locations must have sufficient replacement phones so that users with faulty units are able to have temporary units.

The facilities at the intermediate location must consist of a stock room for replacement components, replacement handsets, and batteries, a workbench to perform the component replacement, a mail room to send out the faulty units and components, and a tool rack to store the required tools needed to replace the components. The producer maintenance facility also needs a mail room and stock room, but they also need a test room for the test equipment to trouble shoot the faulty components, as well as a room to repair and take apart the handsets. Additionally, administrative offices -- since there is only one producer maintenance facility on each continent -- will be located at each producer facility.
5.2 Reliability and Maintenance -- Ground Stations

Because the failure of the ground stations could cause anything from a temporary failure of the network to the catastrophic loss of a satellite, the ground station's reliability must be relatively high. The stations must be able to receive telemetry from and command to the satellites 24 hours a day, 365 days a year. The mean time between failures of the ground station as a whole must be at least 40,000 hours -- roughly once every five years. If a ground station goes down, another station must be able to assume the faulty station's responsibilities within 8 hours. This reliability should ensure that the system's operational readiness is rarely in jeopardy and that the state of health of the satellites can be maintained.

The maintenance of the ground stations will be performed on an on-going basis throughout the year. Periodically, major maintenance activities will need to be performed (such as removing power to certain areas of the station) that will prevent the ground stations from operating as needed. These maintenance activities must be planned in advance to ensure that the system performance is minimally impacted. Also, these maintenance periods must be performed to ensure that the ground stations do not
experience any unexpected failures. When major maintenance activities are required at a ground station, a backup ground station must be available to assume the duties of the ground station that is in maintenance.

5.3 Reliability and Maintenance -- Satellites

The reliability of the satellites is of paramount importance. Unlike the handsets or the ground stations, the satellite cannot be serviced once a problem occurs. (Although the Shuttle Transport System (STS) -- more commonly known as the space shuttle -- is capable of retrieving some satellites, the procedure is extremely difficult and tremendously expensive). For this reason, the components that make up a satellite in this system must be made highly reliable and, unlike the handset or ground station, doubly or even triply redundant.

The satellites must be able to perform their mission for a period of 5 years. While this may not seem like a very high reliability, in the harsh environment of space this is a relatively long time. They must be able to operate 24 hours a day and 365 days a year. The satellites must not be prone to catastrophic failure because replacing failed hardware is not feasible.
It is impossible to talk about satellite maintenance per se since one cannot physically replace or fix parts. However, various pieces of hardware on board the vehicle can be maintained by cycling through different components and by performing calibrations. For instance, batteries can be periodically discharged to prolong life and vehicle attitude reference hardware can be calibrated to ensure optimal performance. Another form of satellite maintenance that can be performed is the launching of additional or replacement satellites. Just as the advances in technology make the prospects of improved portable phones in the future nearly certain, the potential improvements in satellite technology are also very promising. As a result, the system should be able to maintain and improve the performance of the satellite portion of the system as improved technology becomes available.
6.0 Conceptual Design

6.1 Design Alternatives

There are three major components to the satellite based worldwide mobile communications system: the handset, the satellite ground stations, and the satellite configuration.

6.1.1 Design Alternatives -- Handset

The design alternatives for the handset are beyond the scope of this document since the individual handset manufacturing companies will be responsible for both the design and production of the devices. That is, the companies that produce the handset must meet the specified requirements, but how they meet those requirements is the decision of the companies. Thus, these companies must consider design alternatives, but the host company does not.

[NOTE: If different design alternatives for the handset are considered, a trade-off study involving the alternatives should be performed. When performing this study, issues such as the system effectiveness, the life-cycle cost, operational availability and maintainability should all be considered. Before deciding on which of the different
possible designs to select, the relative importance of each issue -- such as maintainability -- should be determined. Then, the design that best meets the criteria established by the weighting of the issues should be selected.

However, the trade-off study is not boundless. In order to establish the bounds of the trade-off study, certain established requirements (such as those presented in section 4.5) are needed. Otherwise, a trade-off analysis could yield potential designs that do not meet the requirements. An example of using the operational requirements to establish the boundaries for the trade-off study on one aspect of the handset is presented in Figure 6.1.1.
Figure 6.1.1. Handset Trade-Off Study Limits Based Upon Operational Requirements.
Some of the other tools available to the system engineer to perform a trade-off study include probability and statistics, modeling and optimization, simulation, and various economic tools and techniques.

6.1.2 Design Alternatives -- Satellite Ground Stations

The design alternatives of the satellite ground stations are dependent upon the satellite configuration selected. For instance, the placement and number of ground stations depends upon the placement and number of satellites. The converse is not true -- the placement and number of satellites will not be dictated by the ground stations. Additionally, the available satellite ground station designs are not nearly as diverse as the satellite designs. For instance, a ground station may need to command and control 5 or 55 satellites. Regardless of how many satellites are deployed, the ground station's basic function is not altered -- it must provide command and control. The actual design of the ground station will be supplied by outside contractors who will submit proposals based upon the established requirements; requirements that will not be fully defined until the satellite configuration is selected.
6.1.3 Design Alternatives -- Satellite Configuration

There are basically two design alternatives for the satellite configuration: a constellation using a series of geosynchronous satellites or a constellation consisting of numerous Low Earth Orbiting (LEO) satellites. Briefly, the geosynchronous constellation's advantages include fewer satellites and a proven communications capability since most communications satellites currently deployed are geosynchronous (or even geostationary). The disadvantages include increased distance to the earth and expensive launch and deployment. The LEO constellation's advantages include the close proximity of the satellites to the earth and the cheaper cost of deployment. The disadvantages include the high number of satellites needed and the fact that a communications constellation such as this has not previously been deployed. The tradeoffs between the two systems are explored below.
6.2 Geosynchronous Satellite Constellation

6.2.1 Geosynchronous -- Advantages

Geosynchronous satellites are proven carriers of long distance communications. The technology required is not new as far as satellite systems are concerned; INTELSAT I (aka EARLY BIRD) handled international telephone traffic and was launched on April 6, 1965 and went operational on June 20, 1965. Since that time, geosynchronous satellites have been used extensively in telephone communications. In fact, most international telephone traffic today is handled by geosynchronous satellites [Pratt, p. 1]. Because of this proven capability and reliability, the geosynchronous satellite constellation appears to be a viable option to implement the global telecommunications system.

Geosynchronous satellites operate at an altitude of roughly 22,300 miles. At this altitude, the satellite's angular velocity is approximately the same as that of the earth. Consequently, the satellite remains roughly above the same spot on the ground. (In the case of a geostationary satellite -- a geosynchronous satellite whose orbit lies in the equatorial plane -- the satellite remains almost exactly above the same spot on the ground.) From this point above the earth, one geosynchronous satellite
can receive and relay signals for most of a hemisphere. If three geosynchronous satellites are deployed and spaced 120 degrees apart and the communication signals are relayed between satellites, the entire world can be covered. This is illustrated in Figure 6.2.1.
Figure 6.2.1. Worldwide Coverage Provided by Three Geosynchronous Satellites
6.2.2 Geosynchronous -- Disadvantages

6.2.2.1 Disadvantages -- Delay

A major consideration in a satellite communications system is the effects of delay and echo. Although the signals travel at the speed of light, the large distances involved in geosynchronous satellite communications do have an effect on the performance of the links. If a three satellite geosynchronous constellation is selected, consider the following situation when two people on opposite sides of the world attempt to communicate:
Figure 6.2.2 Geosynchronous Satellite Constellation – Path Loss Considerations.
Figure 6.2.2 depicts two of the geosynchronous satellites in a three satellite system. \( \Delta \) is the path length between the two satellites, \( r_e \) is the radius of the earth (6370 km), \( r_g \) is the radius of the geosynchronous satellites' orbits (42,164 km), and \( I \) is the distance each user is from their respective satellite.

To find \( \Delta \),

\[
\sin 60 = (\Delta/2)/r_g
\]

is used which yields a value of 73,030 km for \( \Delta \).

To find \( I \), we must use the Law of Cosines, namely

\[
I^2 = r_g^2 + r_e^2 - 2 \cdot r_e \cdot r_g \cdot \cos 30
\]

which yields a value of 36,786 km for \( I \). The total distance the signal has to travel is

\[
\text{total distance} = 2I + \Delta
\]

which yields a value of 146,601 km. This signal travels at the speed of light which is 300,000 km/sec. Ignoring any atmospheric effects, the travel time of the signal from one user to the other is about 490 msec, or over half a second. Factoring in the delays associated with the satellites' on-board processing and the handunits' processing, the delay may increase to as much as 600 msecs.

While this may not seem like a long delay, consider that in the case of speech, the telephone user would have to wait 1.2 seconds after finishing a question to hear the
reply of the person they were talking to. This is quite large compared to the nearly instantaneous response time people are accustomed to on terrestrial links and would undoubtedly be troublesome to some users. To emphasize the irritation that this would cause, consider that the International Telegraph and Telephone Consultative Committee (CCITT) -- which is one of the four permanent branches of the aforementioned ITU located in Geneva -- recommends an upper limit of 400 msecs one-way delay on a voice connection between any two locations in the world [Bleazard, p. 239]. As shown above, the one-way delay using the geosynchronous constellation is approximately 490 msecs without even considering processing delays.

In the case of data transmission, this delay would have major impacts on the response time of interactive types of applications. It would also impact throughput efficiency and error rates in high-volume data transmission applications. For example, if we assume a transmission rate of 6 Mbits/sec and that the data is pumped continually into the satellite channel, then at any given time nearly 4 Mbits of data are "in flight" in one direction or 8 Mbits in both directions simultaneously. Thus, a significant portion of the user's database may be "in flight" at any given time.
6.2.2.2 Disadvantages -- Echo

As the length of delay increases, the effect of echo also increases. Echo is simply when the speakers hear their own voice. Echo suppressors (voice-operated switching devices that determine whether the signal is a speech signal or an echo signal) are built into terrestrial networks to reduce echo effects, but satellite transmissions with their long delays require more sophisticated technology. This new technology is effective for the most part, but does result in clipping (i.e., suppressing or not transmitting) some voice signals. The probability of a signal being clipped increases as the delay increases. [Bleazard, p.38]

6.2.2.3 Disadvantages -- Power

One of the main goals of GCSUPP is to allow users to communicate using handheld units. These handsets must be capable of interfacing with current terrestrial cellular systems as well as directly with the satellites above. This being the case, there are severe power restrictions that need to be considered. If the personal communication unit is to be handheld and capable of communicating directly with a satellite, then the unit must be able to sufficient power to transmit to a geosynchronous satellite.
Consider the Friis equation,

\[ P_r = P_t G_t^* G_r [\lambda / 4\pi R]^2 \]  

(6.2.2.3.1)

where \( P_r \) is the power received at the satellite, \( P_t \) is the power transmitted by the handset, \( G_t \) is the gain of the handset's antenna, \( G_r \) is the gain of the satellite's receiving antenna, \( \lambda \) is the wavelength, and \( R \) is the distance between the handset and the satellite.

Because of current technological limits, the values of \( P_t \) and \( G_t \) are fairly small for the handset; a handset is just not large enough to generate very much power (probably a peak power of under 8 watts) and the antenna gain is nearly unity since the antenna is essentially isotropic. Thus, if the handset's transmitted power is assumed to be roughly the maximum for a handset specified in the operational requirements,

\[ P_t \ast G_t = 8 \text{ W} \]  

(6.2.2.3.2)

is found.

The size of the geosynchronous satellite's antenna cannot be made too large due to physical constraints and, among other issues, cost. (It is extremely expensive to launch a satellite and charges are often by the kilogram).
Currently, the largest fixed antennas on communication satellites have diameters on the order of 30 m (10 feet) and the largest deployed antennas are roughly 10 m (30 feet). In order to find the antenna gain of the satellite,

\[ G_T = \frac{4 \times \pi \times A_e}{\lambda^2} \quad (6.2.2.3.3) \]

is used where \( A_e \) is the effective aperture. \( A_e \) is described by

\[ A_e = \eta \times A_R \quad (6.2.2.3.4) \]

where \( A_R \) is the physical receiving area of the antenna and \( \eta \) is the aperture efficiency of the antenna. Assuming the use of a parabolic antenna, typical values of \( \eta \) are on the order of .5 to .75 [Pratt, p. 110] so a value of .6 is chosen for this example. To find \( A_R \),

\[ A_R = \frac{D^2 \times \pi}{4} \quad (6.2.2.3.5) \]

is used where \( D \) is the diameter of the antenna on the satellite.

Assuming an antenna with a diameter of 10 m is used (which is an extremely large antenna), equation (6.2.2.3.5) yields a value of 78.54 m\(^2\) for \( A_R \). Substituting this value
of $A_r$ and a value of .6 for $\eta$ into equation (6.2.2.3.4) yields a value of 47.12 m$^2$ for $A_o$.

Before substituting a value for $\lambda$ into equation (6.2.2.3.3), the uplink frequency must be converted to wavelength. Recall that the frequency selected for the system is approximately 1.62 GHz, or 1.62E09 Hz (reference section 4.4 (Frequency Selection) of the operational requirements). To convert this frequency to a wavelength,

$$\lambda = \frac{c}{f} \quad (6.2.2.3.6)$$

is used where $c$ is the speed of light -- namely 3E08 m/sec -- and $f$ is the frequency. Substituting 1.62E09 Hz for $f$ and 3E08 m/sec for $c$ into equation (6.2.2.3.6) yields a value of .185 m for $\lambda$.

Now that the wavelength has been found, the gain of the satellite's receiving antenna, $G_r$, can be calculated. Substituting 47.12 m$^2$ for $A_o$ and .185 m for $\lambda$ into equation (6.2.2.3.3) yields a value of 17.301, or 42.38 dB, for the gain of the satellite's receiving antenna.

Substituting $0 \ W$ for $P_t * G_t$, 17.301 for $G_r$, .185 m for $\lambda$, and 35,070 km for $R$ into equation (6.2.2.3.1) yields the power received at the satellite from a handset. This value is 2.33D-14 watts, or -136.32 dBm, or -106 dBm. Despite using an extremely large antenna (10m diameter) on
the satellite, it is a very, very small amount of power that the satellite is receiving.

To further illustrate the power difficulties of implementing this system using geosynchronous satellites, consider the flux density $F$ that is received at the satellite compared to current geosynchronous communications satellites. (The flux density is actually just part of the Friis equation shown in equation (6.2.2.3.1).) Flux density at the satellite is described by

$$F = \frac{P_t \cdot G_t}{4 \pi R^2} \text{ W/m}^2 \quad (6.2.2.3.7)$$

where the elements of the equation are the same as those in the previous equations. In the case of a handset with 8 W of power (which is the maximum expected), equation (6.2.2.3.7) yields a value of 4.28E-16 W/m², or -154 dBW/m², for the flux density $F$. Comparing this value to a typical flux density for an INTELSAT satellite, namely -65 to -75 dBW/m², indicates just how little power is able to be received by a geosynchronous satellite from a portable phone.
6.2.2.4 Disadvantages -- Upgrade Capability

If a geosynchronous satellite constellation is selected, the design of the satellite should be such that there is extreme confidence that the technology used for the satellites will not become obsolete in the near future. The reason for this is that it is extremely expensive to launch a large satellite (and no doubt the satellite's would have to be large in order to have just three vehicles handle so much telecommunications traffic) to an orbit of 22,300 miles. One does not replace such satellites on a routine basis.

Given the recent advances in telecommunications, especially mobile communications, such an assurance against becoming obsolete is not likely. This does not mean that no action should be taken for fear the deployed system will be obsolete. Instead, a manner in which the system can be upgraded to take advantage of the latest technology is desired. A geosynchronous constellation does not offer such flexibility.

6.2.2.5 Disadvantages -- Unavailability of Orbit

While it may seem absurd to consider the vast reaches of space too crowded to deploy another satellite, this is
very much the case for geosynchronous satellites. All geosynchronous satellites reside in an orbit roughly 22,300 miles above the earth and these satellites must be separated to ensure beam interference problems are avoided. Consequently, there are only so many orbital slots available and many of these are already occupied. For instance, a number of geostationary slots available over Africa are already occupied by satellites -- and not one by an African satellite [Powell, p. 208]. Although these interference issues are dependent upon the frequency selected for the satellite link, the probability of the international community agreeing to the deployment of three new geosynchronous satellites is by no means assured.

6.3 LEO Satellite Constellation

6.3.1 LEO -- Description

Implementing a global communications system using LEO satellites is basically deploying an inverting space-based cellular phone system. Instead of the cells remaining fixed as they do with current terrestrial systems (reference section 1.2.3 (Cellular Phone Problems) for how current cellular systems operate), the cells would move along the ground as the satellites pass overhead. This is because the
cells, generated by the satellite's antennas, would be focused on the earth. Instead of the cells remaining stationary and the user moving, a LEO satellite configuration would have the user remaining stationary -- which they would appear to be from a satellite even if the user was driving down a highway -- and the cells moving.

In order to provide worldwide coverage, the LEO satellites must be able to relay data between themselves. Additionally, they must cover the entire globe at any given time. To accomplish this, the LEO constellation would require many (i.e., anywhere from about 20 to 80) satellites, although the actual number is dependent upon the vehicles' altitude. The exact number would be determined in subsequent, more detailed design portions of this system's development if the LEO configuration is selected.

6.3.2 LEO -- Advantages

6.3.2.1 Advantages -- Delay and Echo

A LEO satellite would be deployed at less than 500 miles as opposed to the 22,300 miles of the geosynchronous system. Consequently, the delays experienced are much less than those of the geosynchronous configuration (reference section 6.2.2.1 (Disadvantages -- Delay)). Additionally,
the delays would be well under the CCITT suggested values of 400 msec. Because of the reduced delay, both data and voice communication performance would be nearly that of terrestrial systems and echo effects would be virtually eliminated.

6.3.2.2 Advantages -- Power

As addressed in section 6.2.2.3 (Disadvantages -- Power), power considerations are very important since the system must provide handsets that are capable of transmitting directly to a satellite. As shown in the Friis equation (6.2.2.3.1), received signal power is inversely proportional to the square of the distance from the handset to the satellite. If all other values in the Friis equation are held constant except for \( R \), the LEO constellation represents a significant increase in received power. For example, taking the numbers for the geosynchronous configuration and the LEO configuration and squaring them yields

\[
R^2(\text{Geo}) = (22,300 \text{ miles})^2 = 4.97E08 \text{ miles}^2, \quad (6.3.2.2.1)
\]

and

\[
R^2(\text{LEO}) = (500 \text{ miles})^2 = 25E04 \text{ miles}^2. \quad (6.3.2.2.2)
\]

Taking the ratio of the two values yields

\[
\frac{R^2(\text{Geo})}{R^2(\text{LEO})} = \frac{4.97E08}{25E04} = 1.98E04.
\]
\[ R^2(\text{Geo})/R^2(\text{LEO}) = 4.97 \times 10^8/25 \times 10^4 = 2000. \] (6.3.2.2.3)

Though this is extremely simplified since factors such as some atmospheric effects and the fact that a geosynchronous satellite would probably be deployed with a large antenna are not considered, equation (6.3.2.2.3) indicates that if 1 picowatt were received using the geosynchronous constellation, 2000 picowatts would be received using the LEO constellation. This serves to illustrate that the handset power requirements are more easily met using the LEO constellation.

6.3.2.3 Advantages -- Upgrade Capability

The LEO satellite constellation would be easy to upgrade for two important reasons. One reason is that the satellites are deployed at a low altitude. This would reduce the cost of launching and deploying the satellites thereby making additional launches possible. The second -- and more important -- reason the system could be easily upgraded is the fact that since there would be many satellites, they could be smaller and lighter. Instead of 3 large satellites handling the telecommunications traffic, now there would be something over 60 small satellites. Smaller satellites can be launched much less expensively than large satellites. In fact, they can be launched
without the STS or Titan-type boosters. Recently, Orbital Sciences Corporation has introduced Pegasus, a small rocket designed to place small satellites in orbit. The cost savings are substantial.

6.3.3 LEO -- Disadvantages

The main disadvantage of the LEO satellite constellation is that unlike the geosynchronous constellation, the technology and configuration are unproven. However, the current technology is far enough advanced that the deployment of such a system is feasible.

6.4 Selection of the Satellite Constellation

The two satellite constellations that have been briefly presented for consideration are a system based on three geosynchronous satellites deployed at an altitude of 22,300 miles and a system using multiple (i.e., between 60 and 80) LEO satellites. Each system has advantages and disadvantages, and both are viable options.

The constellation that shall be used is the LEO satellite configuration. The main factors favoring the LEO system are that it imposes significantly fewer power and
antenna gain problems than the geosynchronous constellation and that it is more easily upgraded.

If the system is going to truly deliver global communication using portable phones, the handsets must be able to function effectively with little power and antenna gain. If larger, more cumbersome handsets are necessary -- which they probably would have been if the geosynchronous system were chosen -- the system would not be able to meet the identified need. Thus, the LEO configuration is superior.

The ability to upgrade the system is also of paramount importance. As mentioned previously, advances in mobile telecommunications have increased dramatically in recent years. After all, there were not even cellular phone systems just ten years ago. These advances show no signs of abating; thus, a system that can evolve as new and improved technology becomes available is extremely desirable. The LEO constellation allows inexpensive upgrades, while the geosynchronous does not. Again, the LEO constellation is superior.

Other factors working in favor of the LEO configuration are the virtual absence of delay and echo problems. While not as important as the other factors mentioned previously, it is still desirable to avoid these problems.
The only disadvantage identified for the LEO system is the fact that the configuration and technology is unknown -- nothing like it has ever been tried previously. However, this is not a valid reason to choose another configuration. There is every indication that the deployment of a LEO satellite constellation to provide global portable communication is possible with today's technology: tomorrow's advanced technology -- which is sure to occur -- will only make the system even more efficient and practical. On a more philosophical note, if new and improved systems are not ever deployed, advancements will never occur. Now is the time to design and deploy a LEO satellite constellation that will provide worldwide mobile communications.
7.0 Detailed Requirements

The Conceptual Design presented in section 6.0 established that the GCSUPP will be implemented using a constellation of numerous LEO satellites that will function essentially as a cellular phone system "turned upside down." Unlike current cellular phone systems where a large number of mobile users are served by static cells, the new system will essentially be a large number of static users served by mobile cells. These cells will be projected onto the earth by the LEO satellites.

7.1 Orbital Requirements

The constellation of satellites must be selected to assure that every point on the earth's surface is continuously in line of sight of one or more of the satellites. The orbits should be circular polar orbits and the satellites should be equally spaced around their planar orbits. In order to prevent the satellites from colliding at the poles, a minimum miss radius of 3 miles must be maintained. These satellites must orbit at an altitude no higher than 450 miles. This low orbit will allow deployment with smaller launch vehicles and will allow the handsets to function with relatively low transmitting power.
7.2 Satellite-Based Cells

The satellites should be capable of operating up to 40 cells which are projected onto the earth's surface. Using separate cells will increase spectral efficiency since different cells will be able to reuse frequencies and service different customers with the same channel. This frequency reuse can be accomplished using a technique such as spatial beam separation which incorporates large clustered feeds along with a reflector on an antenna. The combination of horn feeds and a relector allows the creation of shaped beams. In this case, the separation and creation of the cells will be provided by the main mission antenna on board each satellite. Additionally, the dropoff in power from the center of a cell to the edge of a cell should be no more than 3 dB.

The cells should be arranged with one cell in the center surrounded by rings of other cells. All cells should be roughly the same size. Because the cells must cover an entire area with no gaps, circular cells are not acceptable since they will either leave gaps or cause excessive overlap. Instead, the cells should be polygons that approximate circles, such as hexagons. This is depicted in
Figure 7.2.1. Note that there are 37 cells using the hexagon configuration.
Figure 7.2.1. Hexagonal Cells Beamed Onto the Earth.
Hand-off problems associated with cell crossings in current cellular systems will not be as much of an issue in this configuration. In the terrestrial cellular systems, there are many small cells; this configuration has relatively few large cells. The fewer the number of cells, the fewer the number of boundaries, and, consequently, the fewer the number of handoffs required. Additionally, the fact that in this configuration the cells are moving and not the users, the cell boundary crossings can be predicted and computer resources allocated accordingly.

In order to ensure that each cell is serviced by the satellite, the antennas on the vehicle should use a Time Division Multiple Access (TDMA) modulation technique to transmit signals to the various cells. In order to service different users within the cells, a Frequency Division Multiple Access (FDMA) modulation technique should be used. In order to avoid interference from adjacent cells, there must be at least a two cell buffer between cells using the same frequency. In order to accomplish this, the available bandwidth, approximately 16.5 MHz given a frequency range of 1.610 Ghz to 1.6265 GHz (reference section 4.4 (Frequency Selection)), should be divided into at least seven different frequency ranges. This should prevent intermodulation problems between the cells.
7.3 Satellite Crosslinks

In order to provide worldwide coverage, the satellites must be able to support crosslinks. That is, the satellites must be able to relay messages between themselves. Any given satellite in the constellation must be capable of relaying a user call to the satellites adjacent to it in its orbital plane. They must also be able to relay data to at least one satellite in both adjacent satellite planes.

The crosslink frequency will be 20 GHz. A high frequency such as this provides more bandwidth as well as narrower beams thereby reducing the potential for interference. Because the crosslinks will be operating beyond the earth's atmosphere, high frequency considerations such as rain attenuation (again, a factor for frequencies above 10 GHz) need not be addressed.

7.4 Selecting a Communications Path

The GCSUPP must be able to select the least-cost routing for calls. It would be costly and inefficient to beam a call up to a satellite every time someone wanted to place a call to someone else, say, 20 miles away. However, if the network is extremely busy and this is the only means to put the call through, the system must be able to do so.
It must also be able to place calls halfway around the world. The system's performing of these functions should be completely transparent to the user.

7.4.1 Gateways

One of the goals of the GCSUPP is to serve as an enhancement to current telephone systems. Thus, the new system must be able to interface with existing terrestrial networks. These interfaces are termed gateways and provide the necessary means of bridging the gap between the satellite-based network and ground-based networks. The gateway is an integral part of selecting the communications path.

The functioning of a gateway is best described by example. If a GCSUPP user in the Amazon wishes to call someone in Boston that has a fixed phone, the call would be transmitted directly to a satellite, relayed between satellites, downlinked to a gateway serving the Boston area, and then routed to the fixed phone. If the user in Boston has a portable phone, the gateway near Boston will determine where the person receiving the call's handset is located and route the call accordingly. Conversely, if someone in Boston is trying to reach someone in the Amazon that has a portable phone, the gateway serving the Amazon area would
locate the end user and route the call accordingly. Thus, 20 gateways around the world are needed so that calls can be successfully routed. An illustration of the gateway’s relationship to the system is provided by Figure 7.4.1.
Figure 7.4.1. Relationship of Gateways to the Global Communications System.
In addition to the gateways' routing functions, they will also serve as ground stations for commanding and controlling the satellites. These gateways should use the most current artificial intelligence techniques and database management technology to provide a highly automated environment. This will allow a small operations staff to manage the satellite constellation and the gateways.

7.4.2 Communication Unit

As established previously, the communication unit must be portable and capable of communicating directly to the satellites (reference section 4.5 (Communication Unit Requirements)). It also must operate with both terrestrial cellular systems and the satellite-based system. In order to do this, the handset will first scan for the subscriber's terrestrial cellular signal, and will go to the satellite system only if there is no signal available from the local cellular operator. In this way, the handset will function as a conventional -- albeit portable -- cellular phone.

If the communication is routed to the satellites, a means of determining where the receiver is located is needed. This will route the call in the most direct way. To keep track of the locations of the handsets, each unit will include a GPS (Global Positioning System) receiver to
determine its latitude and longitude. When a handset is turned on, it would determine its location via GPS and report its position to an overhead satellite which would in turn relay the information to the nearest gateway. The handset would continue to report its position every 20 minutes. When a call is routed to a handset as in the case of the Amazon-to-Boston example, the call would arrive at the gateway which would know the location of the Bostonian's handset. The gateway would then route the call to an appropriate satellite and to an appropriate antenna beam cell position. Thus, the call will be placed in the most direct manner possible with the gateway serving as part of a satellite-based switching network.

7.5 Signal Type and Data Rates

The system should use the latest communication technology available. In keeping with this philosophy, the system should be designed entirely as a digital communications system. Most current cellular systems are analog, but they are in the process of switching to the increasingly popular digital configuration. The digital configuration is preferred because using techniques such as compression, digital systems can accommodate many more channels in a given frequency range compared to analog
systems. As a result, significantly more users can be accommodated in a cellular system -- nearly three times as many while still using the same spectrum [Burgess, G1]. Additionally, digital transmissions are more compatible for fax machines, computer message traffic, electronic mail, and any data stored in a digital format. Finally, digital transmissions easily accommodate signal encryption -- something analog cellular systems do not -- and they also provide methods for Error Detection And Correction (EDAC).

In order to make the digital system compatible with digital terrestrial systems, coded QPSK (Quadrature Phase Shift Keying) modulation is selected. This digital scheme adds bits to the data stream for the purpose of detecting and correcting errors in received bits. By decreasing the BER (Bit Error Rate), a lower C/N (Carrier-to-Noise Ratio) can be tolerated which will reduce power requirements for the system.

The network must handle both voice and data digitally. Thus, if the system is to interface with existing analog terrestrial networks, coders to convert the analog voice to digital voice will be needed at the gateways. Furthermore, the handunits themselves must have coders. The system should handle data streams at 2400 baud and voice streams at 4.8 kbps.
7.6 Satellites

The satellites that are to be deployed need to be light, power efficient, technologically advanced, and reliable. The satellites must be designed to be deployed using small launch vehicles. Consequently, the size of the satellites must not exceed 8 feet tall by 4 feet in diameter. Each satellite must also weigh under 800 lbs. These dimensions will ensure the satellites can be deployed to their operational orbits using small, relatively inexpensive launch vehicles.

As stated in section 4.8.3 (Reliability and Maintenance -- Satellites), the spacecraft should be designed for a 5 year Mean Mission Duration (MMD). This length of time will ensure that advances in technology can be incorporated in subsequent generations of the satellites, thereby providing a natural evolution as the system matures. In the event that a satellite does fail, a replacement satellite should be deployed within 48 hours. This will minimize the impact on the users. Because a satellite will be replaced with another satellite in the same orbit, the satellites must be designed with a deorbit capability. This will ensure the orbits do not become cluttered with potentially damaging hardware.
8.0 System Functional Analysis

The system functional analysis is best explained in the form of a system functional flow diagram. This diagram is presented in Figure 8.0.1.
Figure 8.0.1. Abbreviated System Functional Flow Diagram.
Conclusion

As communications continue to improve, the world becomes progressively smaller. Radio, television, and telephones have all contributed to this "shrinking" of the world. Today, the events occurring at nearly every location on the globe are communicated to us in real or near-real time, thereby making incidents halfway around the world seem closer than even fifty miles was just a century ago. These communication improvements have been mostly in the realm of mass communications -- one broadcasting to many. Now as we approach the second millenium, a great advancement in personal communications appears within reach.

Global, person-to-person communications using portable phones is no longer the exclusive domain of science fiction writers. It is rapidly becoming a reality. As technology in phones, digital systems, and satellites continues to advance, the prospect of being able to place a direct call to any spot on earth becomes not just possible, but probable. However, this capability will not be achieved in research labs or think-tanks, it will take a massive commercial venture complete with marketing plans, large scale manufacturing, and international cooperation. In order to make this capability happen, a careful, methodical approach is required.
Systems engineering and the systems approach provide the tools for creating such a system. By taking a top-down approach, the big picture of creating a global communications system using portable phones is emphasized as the main goal; not the functioning of each individual component in the system. By using systems engineering, the various engineering disciplines -- and even disciplines outside of engineering -- are brought together to create the optimal system. Establishing the need, the feasibility of developing a system to meet that need, the operational requirements, and the conceptual design in that order, the large, expensive system's development takes shape in a way that ensures the proper system is developed. Failure to take such an approach could result in cost overruns, less than optimal performance of the system, or even a system that simply does not work.

The purpose of this paper was to briefly illustrate some of the first steps needed to develop a global communications system using portable phones. While far from a full scale systems analysis, this paper should have provided the reader with a sense of what issues must be addressed as a major system such as this one is developed from its conception. Coming away from this paper, the reader should have a greater appreciation of what must be
considered to bring a global portable phone system into being.
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