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27 Changing Channels: Voluntary Reallocation of UHF Television Spectrum

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EXECUTIVE SUMMARY

The voluntary reallocation of a single UHF television channel in Los Angeles from broadcasting operations to a third cellular telephone system would likely increase social welfare by over one billion dollars.* The paper proposes that one such voluntary reallocation be permitted in each television market, subject to a streamlined benefit-cost test. It also suggests that such a voluntary reallocation approach could be applied usefully in other areas of the spectrum.

Because the social value of broadcasting service may exceed its market value, it is necessary to estimate social values to determine whether it is socially desirable to shift spectrum to a different use. Our analysis of the social costs and benefits of moving spectrum from UHF television to cellular service involved three basic steps.

First, we calculated the amount of spectrum that would be freed for cellular use by removing a single Los Angeles UHF television station. Even with full protection for all existing and proposed uses of the UHF spectrum, including advanced television (ATV), one of the television stations would yield 18 megahertz of cellular spectrum throughout most of the metropolitan area, and three others would yield 12 megahertz -- each providing enough spectrum for at least a minimal third cellular system using digital technology.

Second, we estimated the social cost of removing the television signal. We calculated that the present discounted value of the change in consumer plus producer surplus for the years 1992-2000 from taking one Los Angeles UHF TV station off the air would be about $139 million. This measure is equivalent to the loss to viewers plus advertisers minus the cost saving from discontinuing broadcasting.

Finally, we calculated the social benefit of the additional cellular spectrum. Based on a simple theoretical model of oligopoly pricing and some empirical evidence from other industries, we would expect cellular prices to fall approximately 25% as the result of introducing a third cellular competitor. Assuming such a price reduction, a third Los Angeles cellular system would produce a social gain of $1.196 billion. This is the present discounted value of the change in consumer plus producer surplus for the period 1992-2000 from such a system using the maximum spectrum that could be released by deleting a Los Angeles UHF television station. Subtracting

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* The research for this paper was substantially completed before the Commission adopted its proposal to issue three to five personal communications services (PCS) licenses in each market. If the Commission adopts this proposal, the value of UHF television spectrum reallocated to cellular telephone service would be substantially reduced. Nevertheless, we believe this paper can provide valuable insights into the concept of voluntary spectrum reallocation and the methodology for estimating the value of spectrum in alternative uses.

the $139 million social cost of deleting a UHF television channel provides a net social gain of $1.057 billion.

In addition to estimating social values, we also estimated market values. Because the market value of the resulting cellular system would be greater than that of the displaced television station, the reallocation would be likely to occur voluntarily if permitted.

Permitting a UHF television licensee to reallocate spectrum to cellular service would represent a departure from past Commission practice. In the past, the Commission has generally accommodated new services or expansions of existing services by newly allocating or reallocating unoccupied spectrum. However, this option has all but disappeared in the most desirable frequency ranges as current usage has increased. This means that the reallocation of occupied spectrum will become increasingly necessary in the future if new services and technologies are to be accommodated. To avoid the long delays that would be involved in reallocating occupied spectrum, the Commission has recently proposed the voluntary reallocation of spectrum in the "emerging technologies bands" between 1.85 and 2.20 GHz.

The paper recommends that the Commission adopt a limited voluntary reallocation policy for UHF television spectrum. Because the market value of a television station represents only a fraction of its social value, an unrestricted voluntary policy could result in an excessive reallocation of spectrum and a reduction in social welfare. To minimize this risk, the paper suggests that only one UHF television station per market be authorized to reallocate the spectrum it occupies and that this spectrum be used for the establishment of a third cellular system.

Further, because not all possible reallocations, even if so restricted, would produce a net gain in social welfare, the paper recommends that each application be required to pass a simplified benefit-cost test. The primary factors considered in the calculation would be: (1) the amount of spectrum made available for cellular; (2) the demand for cellular service in the area where spectrum becomes available; (3) the prices charged by the incumbent cellular operators; (4) the number of television stations in the market; (5) the number of households served by the displaced television station; and (6) the percentage of such households passed by cable.

The paper also recommends that voluntary reallocations be applied more broadly. Where broadcasting is not involved and the concern about market failure is less, it should be possible to dispense with individual benefit-cost tests and rely entirely on a voluntary process for the reallocation of occupied spectrum. Voluntary reallocations would speed the introduction of new services and technologies and increase competition in a wide range of existing telecommunications services where new entry is not now possible because of spectrum unavailability.

I. INTRODUCTION AND SUMMARY

Through a case study, this paper provides evidence that spectrum is not efficiently allocated under the current administrative approach to spectrum management. We found that the voluntary reallocation of a single ultra high frequency (UHF) television channel in Los Angeles to create a third cellular telephone system would likely increase social welfare by over one billion dollars.[1] The paper proposes that one such voluntary reallocation be permitted in each television market, subject to a streamlined benefit-cost test, and suggests that such a voluntary reallocation approach could be applied usefully in other areas of the spectrum.

We chose to study UHF television and cellular telephone service not only because data were readily available for these services, but because increases in cable television penetration and the rapid growth in the number of cellular subscribers suggested that the social value of spectrum used in broadcast television has declined relative to its value in cellular service. The large disparity in market values -- with cellular franchises trading at about thirty times as much as UHF television stations per megahertz of spectrum -- also indicated a possible misallocation.[2]

Examining market values is not sufficient to make policy judgments, however, because of the possible divergence between the social and market value of broadcasting services. To determine whether it is socially desirable to shift spectrum to a different use it is necessary to estimate social values. Our analysis of the social costs and benefits of moving spectrum from UHF TV to cellular service involved three basic steps. First, we calculated the additional amount of spectrum that could be used for cellular if one Los Angeles television signal were removed; second, we estimated the social cost of removing the television signal; and then we calculated the social benefit of the additional cellular spectrum.

Our analysis confirmed the preliminary evidence that a significant misallocation of UHF spectrum exists between television broadcasting and cellular telephone service. It suggests that a relatively small shift of spectrum from television broadcasting to a third cellular system in Los Angeles would produce a large net gain in social welfare. Because the market value of the resulting cellular system would be greater than that of the displaced television station, the reallocation would be likely to occur voluntarily if permitted.

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[1] The first benefit-cost study of spectrum allocation that we know of was a 1985 report by Transcomm, "The Net Benefits of Assigning Additional Electromagnetic Spectrum to Cellular Radio Telecommunications: Report to Telocator Network of America and Cellular Telecommunications Industry Association" (Falls Church, Virginia: Transcomm, Inc., 1985). It compared the social value of 12 MHz of spectrum allocated alternatively to cellular telephone service and land mobile satellite service and concluded that net social benefits would be $1.7 billion greater by allocating the spectrum to cellular service

[2] See table 1.

By relyng on private initiative and market forces to implement a pre-approved reallocation objective, the recommended policy would represent a measured departure from past Commission practice. In the past, the Commission has generally accommodated new services or expansions of existing services by newly allocating or reallocating unoccupied spectrum. In rare cases the Commission has reallocated occupied spectrum and moved existing users to other bands after a period sufficiently long to amortize their investments. But the Commission has never permitted an existing licensee to voluntarily discontinue providing the service for which it was licensed and provide a completely different service with the spectrum that was occupied by the old service.[3]

The paper recommends that the Commission adopt such a policy for UHF television spectrum. However, the paper does not propose giving broadcast licensees unlimited reallocation authority. Because the private (market) value of a television station represents only a fraction of its social value, there is a real concern that an unrestricted voluntary policy could result in an excessive reallocation of spectrum and a reduction in social welfare. To minimize this risk, the paper suggests that only one reallocation of UHF spectrum be authorized per market and that a requirement be imposed that the resultant spectrum be used specifically for the establishment of a third cellular system. Further, because not all possible reallocations, even if so restricted, would produce a net gain in social welfare, the paper recommends that each application be required to pass a quantitative but simplified benefit-cost test derived from the analysis presented in this study. The quantitative results of the test would also provide an objective means of choosing among competing applications in the event that more than one is proposed in a market.

The paper also suggests that a voluntary reallocation approach be applied more broadly. Where broadcasting service is not involved and the concern about market failure is less, it should be possible to dispense with the individual benefit-cost tests and rely entirely on a voluntary process for the reallocation of occupied spectrum from existing to newly authorized services. This would increase competition for a wide range of existing telecommunications services and speed the introduction of innovative radio services and technologies.

AMOUNT OF SPECTRUM AVAILABLE

The first step of our analysis involved determining the areas where cellular radios could operate without interfering with television viewers. While a television station nominally occupies six megahertz (MHz) of spectrum bandwidth, interference-free reception of that station precludes cellular use in the same geographic area not only of the channel it occupies but of the two

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[3] However, the Commission has recently adopted a limited form of voluntary reallocation of spectrum in the "emerging technologies bands." First Report and Order and Third Notice of Proposed Rule Making, ET Docket No. 92-9, FCC 92-437, September 17, 1992.

cellular use in the same geographic area not only of the channel it occupies but of the two adjacent channels as well. Therefore, removing a UHF television station could release as much as 18 megahertz of spectrum (three TV channels) for cellular service. However, because of the need to protect the reception of other television stations in the area on the same or adjacent channels, the actual amount of cellular spectrum produced by removing a particular television station can vary over different portions of the area from as little as none to as much as 18 megahertz.

Protecting all existing and proposed uses of the UHF band, including advanced television (ATV), we found one UHF television station serving the Los Angeles area which, if removed, would yield the full 18 megahertz of potential cellular spectrum throughout most of the metropolitan area, and three others that would each yield 12 megahertz. Protecting only existing uses, three television stations would each yield 18 megahertz of cellular spectrum throughout most of the metropolitan area, and five would yield 12 megahertz. As we discuss below, 12 megahertz is more than enough spectrum for a viable third cellular system using digital technology.

SOCIAL LOSS FROM LOSS OF TELEVISION SERVICE

We estimated that the social loss from taking one Los Angeles UHF TV station off the air would be about $139 million. This was measured as the present discounted value of the change in consumer plus producer surplus for the years 1992-2000. This measure is equivalent to the loss to viewers plus advertisers minus the cost saving from discontinuing broadcasting. A model developed by Noll, Peck, and McGowan (1973) was used to estimate the loss to consumers not subscribing to cable.[4] We assumed that households subscribing to cable incur no loss when a broadcast station is taken off the air. This would be the case if the television station which went off the air continued to provide the cable system with the same programming, including local advertising. Alternatively, the cable system might substitute a station with programming virtually identical to that of the station going off the air.

SOCIAL BENEFIT OF NEW CELLULAR SPECTRUM

We calculated the social benefit of allocating the newly available spectrum to the two existing cellular operators and, alternatively, to a third cellular operator. This too was measured by the change in consumer plus producer surplus. One way to express this is as the reduction in the cost of providing the initial level of cellular service, plus the benefit to customers of the

[4] Roger Noll, Merton Peck, and John McGowan, Economic Aspects of Television Regulation (Washington, D.C.: The Brookings Institution, 1973).

expansion in total service minus the cost of providing that additional service. This analysis was an extension of work by Hatfield and Ax, who considered only the first of these three effects.[5]

The degree to which prices for cellular airtime fall and output expands as a result of additional spectrum is critical in determining the benefit of allocating additional spectrum to cellular services. Assuming that cellular output expands by the same percentage as price is reduced (i.e., that price elasticity is unitary), only a modest price reduction is needed for reallocating spectrum to increase social welfare. If 18 megahertz of newly available spectrum were divided evenly between the two existing cellular operators, a one percent price reduction would be sufficient. If the spectrum were used to create a third cellular system, a 3.5% price reduction would be needed, because of the additional cost of new facilities.

Of course, we would expect the price reduction to be much greater if the spectrum were used to create a competing third system rather than dividing it between the existing operators. Based on a simple theoretical model of oligopoly pricing and some empirical evidence from other industries, we would expect cellular prices to fall approximately 25% as the result of introducing a third competitor. In this case, considering only the period 1992-2000, and limiting the new cellular system to the Los Angeles market, we estimated that the gain in consumer plus producer surplus from creating such a system would be about $922 million. Subtracting the estimated $139 million social value of a UHF station produces a net social gain of $783 million.

The major source of these social benefits would be increased cellular competition. Assigning less spectrum to a third system would increase its cost, but approximately the same price reductions could be expected. Assuming the same 25% price reduction, if the amount of cellular spectrum is reduced from 18 megahertz to 12 megahertz, the net social benefit of a third cellular system would be $754 million. With 6 megahertz the net social value of a third cellular system would fall to $660 million, again reflecting the higher costs.

Refining our analysis to allow for the fact that potential cellular spectrum occupied by a Los Angeles UHF television station may extend beyond the Los Angeles market and vary over that larger area produced somewhat larger benefit estimates. Assuming that the spectrum released would be used by a third cellular system, and that all current and proposed future uses of the UHF spectrum, including ATV, would be protected from interference, we estimated a net social gain of $1.057 billion from reallocating one UHF television channel to cellular use.

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[5] Dale Hatfield and Gene Ax, "The Opportunity Costs of Spectrum Allocated to High Definition Television," paper presented at the Sixteenth Annual Telecommunications Policy Research Conference, Airlie House, Airlie, Virginia, October 30, 1988.

MARKET VALUES OF SPECTRUM

In addition to estimating social values, we also estimated market values. Our estimate of the market value of spectrum used in broadcasting was based on recent sales prices of UHF TV stations serving the Los Angeles area.[6]

The market value of cellular spectrum was calculated as the increase in the present value of after-tax profits of existing cellular operators from using the newly available spectrum divided equally between them, or alternatively as the present value of after-tax profits of a third cellular system assigned all the additional spectrum. Each case was estimated both with and without price reductions and associated output expansion.

In all cases we found that the market value of the spectrum would be greater in cellular telephone use than in UHF TV broadcasting, meaning that unfettered markets would shift spectrum from television to cellular service. Such a voluntary reallocation of spectrum from UHF TV to cellular might not occur, however, if other spectrum were to become available for a service, such as PCS, which would be highly competitive with cellular. Of course, in this case a reallocation would be less likely to increase social welfare since the benefit of additional cellular competition would be diminished.

EXTENSION TO OTHER MARKETS

While our analysis only covered the Los Angeles area, we did estimate the marginal social value of a UHF TV station under alternative counterfactual assumptions about the percent of homes passed by cable and number of over-the-air TV stations. We found, for example, that even if the Los Angeles market had only seven over-the-air stations (instead of the current 16) and only 70% of homes were passed by cable (instead of the projected 90% for 1992), reallocating a UHF TV channel to cellular would still increase social welfare. With suitable adjustments for market size, such calculations can be used in estimating the social costs of removing a TV station in markets with different combinations of TV stations and homes passed.

In addition, we found that the benefit of creating a third cellular system is sensitive to cellular prices in a market. Using projected cellular prices for a typical cellular market, the social value of a third cellular system was estimated to be less than half the value based on the relatively high prices we forecast for the Los Angeles market. These reduced estimates, adjusted

6 It was significantly less than the social value, since the market price reflects only the value advertisers place on reaching viewers, and not the value viewers place on programming.

for differences in market size and the amount of spectrum available, can be used to approximate the benefits of creating a third cellular system in markets with average cellular prices.

POLICY RECOMMENDATIONS

The final part of the study is a discussion of a policy to allow the creation of additional cellular providers through the voluntary reallocation of UHF spectrum. We propose that the Commission permit the discontinuation of one commercial UHF television station per market with the released spectrum used for a third cellular system -- provided that the change can be justified on the basis of a benefit-cost test of the kind developed here. That is, the reallocation would be permitted only if the estimated social value of the resultant third cellular system would exceed that of the displaced television service. The primary factors considered in the calculation would be: (1) the amount of spectrum made available for cellular, (2) the demand for cellular service in the area where spectrum becomes available, (3) the prices charged by the incumbent cellular operators, (4) the number of television stations in the market, (5) the number of households served by the displaced television station, and (6) the percentage of such households passed by cable.

We also propose that the policy be implemented only after the ATV planning process is completed and that it not apply to ATV channels. Thus the policy would not compromise the development of ATV.

This approach could be applied more broadly than permitting exchanges of UHF TV licenses for cellular licenses. The procedure addresses the general problem of reallocating assigned spectrum. It creates incentives for the private sector to identify and implement spectrum reallocations that increase social welfare. In the past, the Commission generally has been able to meet most new demand by allocating vacant spectrum. But now virtually all spectrum of value has been allocated to specific services. If the Commission is to accommodate a new service or give an existing service more spectrum it must therefore reduce the amount of spectrum used by some other existing service. Doing this without compensating existing licensees is likely to be a time-consuming and difficult process. Our proposal would automatically provide such compensation through privately negotiated arrangements and thus may be the fastest way to provide the public with the benefits of new radio technologies and innovative uses of the spectrum.

II. MARKET VS. SOCIAL VALUE OF SPECTRUM

Table 1 provides a back-of-the-envelope calculation of spectrum values in Los Angeles based on market transactions. The large disparity in per-megahertz values provides preliminary evidence that spectrum is not efficiently allocated.[7] However, it may not be sufficient to examine market values to determine whether an allocation is efficient because market values may differ from social values. There are a number of reasons this is so.

The first is unique to broadcasting. Broadcasters generally obtain their revenues by selling advertising. They do not bill viewers directly. The profits earned by broadcasters, and the market value of a broadcasting license, reflect only the value advertisers place on reaching viewers, and do not include the value viewers place on programming. But the social value of advertiser-supported television includes both the value to advertisers and the value to viewers. Omitting the value to viewers may seriously understate the social value of broadcasting. In their 1973 study, Noll, Peck, and McGowan estimated that the value of over-the-air television to viewers was about seven times total television advertising revenue.[8]

Even if broadcast television were viewer financed (like cable), the market value of a license might not equal its social value. The source of the problem is that licenses are a "lumpy input," so that the entry of a licensee into a market may cause a significant change in output relative to the size of the market.[9] This contrasts with a perfectly competitive market in which each firm supplies a very small share of the market output of a homogeneous commodity. In such a perfectly competitive market, the entrance or exit of an individual firm has no discernible effect on market price, and thus is of no consequence to consumers or other firms. In the markets we are considering, however, the entrance or exit of a licensee can make a significant difference to consumers and other firms. And the licensee's decisions may not maximize social welfare because profits may not fully reflect the impact on these other parties.

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[7] In section V of the paper we use an alternative methodology to estimate the market value of additional spectrum both to existing cellular operators and to a third cellular operator. Instead of relying on recent market transactions we conduct a cash flow analysis. We estimate the amount a firm would pay for additional spectrum as the increase in the present discounted value of after-tax profits attributable to that spectrum.

[8] Roger Noll, Merton Peck, and John McGowan, Economic Aspects of Television Regulation (Washington, D.C.: The Brookings Institution, 1973), p.23.

[9] See Severin Borenstein, "On the Efficiency of Competitive Markets for Operating Licenses," The Quarterly Journal of Economics, (May 1988), 357-385. Michael Spence and Bruce Owen, "Television Programming, Monopolistic Competition, and Welfare, Quarterly Journal of Economics, 91 (Feb. 1977), 103-127. Michael Spence, "Product Differentiation and Welfare," American Economic Review, 66 (May 1976), 407-414.

Table 1: Rough Estimates of Spectrum Values in Los Angeles Based on Market Transactions

UHF TV (Operates on 6 MHz per station)

Station Traded*	Year Traded	Trading Price ($ millions)	Value per MHz ($ millions)
Stations Covering Downtown			
KHSC -- 46 Ontario, CA	1986	35.0	5.8
KVEA -- 52 Corona, CA	1985	30.0	5.0
Station Covering Fringe Area			
KTIE -- 63 Oxnard, CA	1987	5.5	0.9

CELLULAR TELEPHONE (Operates on 25 MHz per system)

Cellular Transaction**	Reported Value Per Pop. ($)	Total Value of LA Franchise (value per pop x 13 million ($ millions)	Value per MHz ($ millions)
BT/McCaw (2/89)	138	1,794	71.8
Bell Atlantic/Metro Mobile (9/91)	202	2,626	105.0
McCaw/Lin (12/89)	320	4,160	166.4

NOTES:

* Data represent all commercial UHF TV stations trading in L.A. from 1985 to 1988. Prices for channels 46, 52, and 63 respectively were from the following issues of Broadcasting: Feb. 8, 1988; Feb. 9, 1987; and Jan. 27, 1986. There were no trades in L.A. in 1988 according to Broadcasting, Feb. 13, 1989.

** Cellular trades are reported in terms of the value per person (per "pop") in the franchise area. When a company does not own an entire franchise, a pop is defined as the total population in the franchise area, multiplied by the company's ownership share of the cellular franchise. The estimate of the per pop value of the BT acquisition of 22% of McCaw was reported in Business Week, "Craig McCaw Goes Establishment," February 6, 1989, p. 40. The Bell Atlantic acquisition of Metro Mobile CTS was reported in The New York Times, "Bell Atlantic Takes a Mobile Leap," Sept. 25, 1991, p. D1. The McCaw acquisition of Lin was reported in The Wall Street Journal, "McCaw Appears to Have Won Fight for LIN," December 5, 1989, p. A3.

To illustrate this potential market failure, consider the case where entry of a licensee matters to consumers, but has no effect on other firms. For example, suppose a subscription television station is considering entering a market that has no other stations. The station will charge viewers a subscription fee (for a descrambler). From a social perspective the station should enter the market if the total amount viewers would be willing to pay is greater than the cost of running the station. Even if this condition is met it may not be profitable for the station to enter the market. The problem is that the broadcaster has no way to charge each viewer the maximum amount he would be willing to pay. With a uniform subscription fee only the marginal customer pays the maximum amount he is willing to pay. The inframarginal customers pay the same amount but would be willing to pay more. Thus, the profits from entering the market would be less than the social value of entry, and socially beneficial entry may not occur.

This problem would not occur, however, if each firm produced an infinitesimal output. In that case, a new entrant serves only the marginal customer and generates no consumer surplus on inframarginal units of output. The firm is able to capture the social value of entry because the equilibrium market price equals the value of output to the marginal consumer.

If entry affects other firms, the opposite situation may arise, i.e., profits may exceed the social value of entry. To illustrate this, suppose a broadcaster enters a market that already has several stations, and attracts most of his audience from other stations. The change in social welfare is the increase in consumer benefits from the additional programming choice, plus the profits of the new station, minus the reduction in profits of the incumbent stations. It is possible that the loss in profits to other stations could outweigh the profits to the new entrant and the added benefits to consumer. This is more likely to occur in broadcasting than for other services because the cost of providing a broadcast signal is independent of the number of viewers. When a station's audience shrinks there is no saving in costs, merely a reduction in revenues.

These last two types of market failure may apply to all FCC licenses. For example, the profits from entering the cellular market may either exceed or be less than the change in social value (consumer plus producer surplus). They may exceed it because part of the profits of a new entrant may come from incumbents. They may be less because cellular operators are not able to capture the entire value consumers place on their services.

The fact that certain markets do not always operate optimally does not necessarily imply that they should be regulated. The potential market failure associated with lumpy investments applies to most markets to some degree, yet few would propose a broad expansion of government oversight to ensure that all market transactions increase social welfare. Government regulation is costly and imperfect, so one cannot presume that such regulation will result in a net increase in social welfare.

The analysis in this section simply implies that allowing the free market to allocate spectrum among services may not always maximize social welfare. The profits from using a block of spectrum to provide mobile services may exceed the profits from using that block to provide UHF TV, yet social welfare might be higher if the spectrum were used in UHF TV. The remainder of this paper examines whether such a market failure would be likely or whether, in practice, social welfare could be increased by allowing the market to operate.

III. QUANTIFYING CELLULAR SPECTRUM RELEASED BY THE DELETION OF A UHF TELEVISION CHANNEL

A. INTRODUCTION AND SUMMARY

Suspending operation of a full power UHF television station would release spectrum which could then be reallocated to cellular service. This section develops a methodology for calculating the amount of cellular spectrum that would be released and presents the results of applying that methodology in the Los Angeles case study. The value of this released cellular spectrum is calculated in sections V and VI.

To visualize what it means to "release" cellular spectrum by removing a UHF television station, imagine that cellular service is permitted throughout the UHF band in all areas where it does not cause interference to other uses of the band. Knowing the technical characteristics and locations of existing uses, including UHF television, it would be possible to draw a map of a metropolitan area, such as Los Angeles, showing areas where cellular service is precluded on each channel because of potential interference. Now suppose that one of the UHF television stations in the area were removed. The precluded area on certain channels would shrink, providing a visual representation of the cellular spectrum released by removing the station.

Each full power UHF television station precludes cellular service on three contiguous 6 megahertz-wide channels (the channel on which the station operates plus the two adjacent channels) over a large area. Cellular operation is precluded on this spectrum because of potential interference to and from the television station. However, removing the television station will not necessarily free all of this spectrum for cellular use. This is because portions of the same spectrum can also be precluded by other nearby stations, particularly in congested areas like Los Angeles. Therefore, the removal of a single television station can be expected to release different amounts of cellular bandwidth, i.e., either zero, one, two, or three television channels, over different portions of the area.

For the Los Angeles case study, a computer program was written to calculate the bandwidth (i.e., number of 6 MHz channels) released within a 104.5 mile radius of Los Angeles by individually deleting UHF television stations within a 40 mile radius. Released spectrum was calculated at existing wireline cell sites to relate spectrum availability to cellular demand.[10]

[10] Two cellular systems are authorized in each area, one to a subsidiary of the local telephone company (the "wireline" system) and one to another firm. Either of the two cellular systems could have been used in our calculations since both have approximately the same geographic distribution of cell sites. At the time the data were obtained, there were 138 wireline cell sites within the study area, of which 100 were licensed to the Los Angeles operator. The size of the study area and other distances use in our calculations are explained in more detail below.

The program used a simplified interference model and a database of all UHF uses within a 200 mile radius of Los Angeles. For visual verification, the program also produced maps showing the location of the cell sites and the amount of cellular bandwidth available over different portions of the area before and after the deletion of a particular station.

Calculations were done for each of the thirteen stations within the 40 mile radius. (See list in appendix C.) Stations farther out were not analyzed to ensure that most of the released spectrum would fall inside the study area. The calculations were repeated under two policy scenarios with different assumptions about the protection of other uses of the band. First, we assumed that existing as well as proposed uses would be protected, including a large number of additional channels for future advanced television (ATV) service.[11] We then assumed that only existing uses of the band would be protected.

As we had expected, the amount of released spectrum varied significantly depending on the particular station deleted and the protection afforded other uses of the band. With protection of existing and future uses, four of the deletions released 12 MHz of bandwidth (two channels) at more than half of the cell sites and one of those deletions released 18 MHz (three channels) at approximately half of the sites. With only existing uses protected, eight deletions released 12 MHz at most cell sites and three of those released 18 MHz at more than half of the sites.

The results of these calculations are presented and discussed in greater detail at the end of this section following a description of the interference model and computer programs used. To provide a background for those calculations, it would be useful to review the current use of this band and, in particular, its use in the Los Angeles area.

B. CURRENT ALLOCATION AND USE OF THE UHF TELEVISION BAND

The UHF television band comprises the range of frequencies between 470 and 806 MHz and is divided into 56 six megahertz-wide television channels, designated channels 14 through 69. The principal current use of this spectrum is full power broadcast television service operating under the current NTSC transmission standard. However, there are several other current and proposed uses which must be taken into account in our calculations. In particular, one channel

[11] The current NTSC television system is named after the National Television Systems Committee that developed it in the 1940s and 50s. ATV is a generic term encompassing both HDTV (high definition television) which would provide picture quality comparable to 35 mm film but could not be viewed on current TV receivers and EDTV (enhanced definition television) which would provide less of an improvement in picture quality than HDTV but would be viewable on current TV sets.

(channel 37) is reserved exclusively for radioastronomy use nationwide; two channels (three in Los Angeles) are allocated for conventional, non-cellular land mobile use, such as police and commercial fleet operations, in the 13 largest metropolitan areas (this allocation is often referred to as land mobile sharing); and low power television service is authorized throughout the nation on all channels, except the radioastronomy and land mobile sharing channels, provided it does not interfere with full power service. In addition, the FCC has proposed to allocate additional land mobile sharing channels in the eight largest metropolitan areas, including six channels in Los Angeles, and is considering allocating a large number of channels nationwide for ATV service. Following is a brief description of each of these services, their current use of the UHF band in the Los Angeles area and our assumptions about interference protection under the two scenarios considered.

1. Full Power Television Service.

To prevent interference between television stations, FCC rules specify minimum distance separations between full power television stations depending on their channel separations. Stations on the same channel (co-channel) must be separated by distances ranging from 155 to 205 miles depending on geographic region; stations on the immediately adjacent channels by at least 55 miles; and stations two, three, four, five, seven, eight, fourteen and fifteen channels apart (the so-called "taboo" separations) by distances ranging from 20 to 75 miles.[12]

The number of UHF channels available for full power television service in an area is affected not only by minimum distance separations but also by FCC channel allotment policy.[13] Federal law requires an equitable distribution of broadcast channels among the states and communities.[14] To implement this requirement, the FCC has allotted specific channels to communities and licenses stations only on those channels.[15] This administrative allotment of channels coupled with the minimum distance separations discussed in the preceding paragraph limits the number of UHF channels that can be used for full power television service in any area.

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[12] The distance separation rules are found in 47 CFR 73.610 and 73.698.

[13] In FCC spectrum management parlance, television channels are "allocated" to services, "allotted" to communities and "assigned" to individual stations.

[14] Communications Act of 1934, as Amended, 47 U.S.C. 307(b).

[15] See, "Table of Allotments", 47 CFR 73.606(b).

A list of the full power channel assignments and vacant allotments included in our Los Angeles database is included in appendix C.[16] All full power assignments and vacant allotments within the 200 mile radius were considered to be "existing uses" and were assumed to be protected under both policy scenarios.

The Commission's rules permit the allotment of additional television channels to a community if minimum distance separations are met. Therefore, it is possible that additional full power allotments could be made in the general Los Angeles area which could change the results of our study. If such additional allotments were made, the amount and therefore value of cellular spectrum released by particular deletions could be less than what we have calculated. However, considering the large number of existing channel assignments in the area and the high value of a television station with Los Angeles coverage, it is likely that any potential for additional allotments close to the city has long since been exhausted. A new allotment in the outlying areas would have less of an effect on cellular spectrum released within the Los Angeles cellular market.

2. Low Power Television Service.

The UHF band is also allocated nationwide on a secondary basis to the low power television (LPTV) service, which means that LPTV stations may not cause interference to, and are not protected from, existing and future full power stations. Unlike full power stations, LPTV stations are not subject to an allotment plan or fixed mileage separations and can be authorized on any channel (except the land mobile and radioastronomy channels) if calculations show that interference will not occur.

This licensing flexibility coupled with lower power means that operation of LPTV stations may be possible at locations precluded to full power stations. However, in Los Angeles it would appear that the large population of full power stations and other uses of the band have effectively precluded LPTV stations throughout the central portion of the area. Our database (see appendix C) shows no LPTV stations within 30 miles of Los Angeles and only 2 within 60 miles, despite the economic incentive to locate as close as possible to the center of the city. However, there are many LPTV stations located in the less congested area beyond 60 miles, and additional LPTV stations may be possible in these fringe areas. Under both policy scenarios examined in this study, we assume that existing low power stations would be protected from interference from cellular operations.

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[16] A vacant allotment could also be deleted to release spectrum for cellular service. However, we found no vacant allotments within 40 miles of Los Angeles, and, as indicated above, we did not consider possible deletions beyond 40 miles.

3. Land Mobile.

In addition to full power and low power television service, land mobile operation is currently authorized on certain UHF channels in the 13 largest U.S. cities. This provision is often referred to as land mobile sharing.[17] Land mobile sharing is authorized in Los Angeles on channels 14, 16 and 20. In 1985, the FCC proposed to allocate additional UHF channels for land mobile sharing in eight of the largest metropolitan areas, including an additional six channels in Los Angeles.[18] The current and proposed land mobile sharing channels in Los Angeles are listed in appendix C. Under scenario 1, we assume that all of the current and proposed land mobile sharing channels would be protected from cellular interference. In scenario 2, only the existing land mobile channels would be protected.

4. Advanced Television.

Once a transmission standard for ATV is selected and ongoing planning studies are completed, it is anticipated that channels will be allocated for ATV use in the UHF television band. While a final plan has yet to be announced, one plausible outcome would be to pair an ATV channel with each of the existing full power NTSC channel allotments so that service can be provided in both formats during the period of transition to ATV.[19]

To do this in a congested area like Los Angeles will require that ATV stations operate with shorter distance separations than currently provided between NTSC stations. This implies that ATV stations will be more tolerant of interference and less likely to cause interference than are NTSC stations. One FCC study found that if ATV stations can operate satisfactorily with only 100 miles of co-channel separation and no adjacent or taboo channel separations, then it would be possible to pair an ATV channel with virtually all (99.6%) of the existing NTSC allotments in the United States.[20]

To model the effect of a future ATV allocation, we included in our database a hypothetical set of ATV channel allotments within 200 miles of Los Angeles (see list in appendix

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[17] First Report and Order, Docket No. 18261, 23 FCC 2d 325 (1970).

[18] See, Notice of Proposed Rulemaking, Docket No. 85-172, 101 FCC 2d 862 (1985). Final disposition of this proposal has been deferred pending the allocation of UHF channels for advanced television service. See, Order, 2 FCC Rcd 6441 (October 1987).

[19] See FCC MM Docket No. 87-268, Tentative Decision and Further Notice of Inquiry, 3 FCC Rcd 6520 (1988) and First Report and Order, 5 FCC Rcd at 5626, 5627 (1990). See also note 11, supra.

[20] OET Technical Memorandum, FCC/OET TM89-1 (Dec. 1989), at 10-11, 65 and 66.

C). These allotments were provided by the FCC's Office of Engineering and Technology based on the separation assumptions cited in the preceding paragraph. Allotments were generated for an area larger than that covered by our study, and those within 200 miles of Los Angeles were added to our database.[21] Under policy scenario 1, these hypothetical ATV allotments were treated as though they were additional full power NTSC allotments but were given co-channel protection only. The ATV allotments were not protected under scenario 2.[22]

C. THE INTERFERENCE MODEL

To calculate the amount of potential cellular spectrum released by the deletion of a full power television assignment requires a model for calculating interference between cellular and UHF television. We know of no studies directed specifically at this question. However, similar interference effects were studied extensively in the development of the land mobile sharing provisions discussed above.[23] Since land mobile and cellular technologies are very similar, the land mobile interference criteria should also be applicable to cellular. We therefore used the current land mobile sharing criteria, adjusted to reflect the lower power levels and different system configuration used in cellular, as the basis for our spectrum calculations.[24]

The land mobile sharing studies indicate that interference could occur to television from cellular transmissions on not only the channel assigned to the television station (co-channel) but also on the channels immediately above and below (adjacent to) the assigned channel. Thus, a television signal on channel N would be subject to interference from cellular transmissions on channels N-1, N and N+1. A lesser possibility also exists for interference from cellular transmission on certain of the taboo channels. Under current land mobile sharing rules, a distance separation of 1 mile is provided between land mobile base stations and television stations on certain of these channels. However, in the more recent Commission proposal to allocate additional sharing channels, these taboo channel separations were omitted. Because

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21 Each ATV allotment was given the same coordinates as its corresponding NTSC assignment or vacant allotment.

22 An actual allotment of ATV channels different from our hypothetical allotment would probably result in different amounts of spectrum being released on particular channels but probably would not change the overall results or conclusions of our study. This would also be true if more ATV allotments are made in the area than there are existing NTSC allotments. The possibility of such additional ATV allotments would be limited by the current heavy use of the band in the area.

23 The interference criteria for existing land mobile sharing are set forth in 47 CFR 90, subpart L.

24 Interference is also possible from television to cellular. However, our analysis in appendix A suggests that the spectrum precluded to cellular because of such interference would also be precluded because of interference from cellular to television and therefore need not be separately calculated.

cellular transmitters radiate significantly less power than conventional land mobile, the potential for taboo channel interference would also be less. Consequently, we assumed that only co-channel and adjacent channel separations would be required.[25]

The severity of interference that would be experienced by a television receiver as a result of co-channel or adjacent channel cellular signals is a function of the relative strength of the electromagnetic fields produced by the "desired" (television) and "undesired" (cellular) transmitters (the so- called D/U ratio) at that receiver. Current land mobile sharing is based on maintaining a minimum D/U ratio of 50 dB (co-channel) and 0 dB (adjacent channel) throughout the protected television service area.[26] In the further sharing proposal, a lower co-channel ratio of 40 dB was proposed. To be conservative in our estimation of cellular spectrum availability, we used the current 50 dB ratio.

To maintain minimum co-channel and adjacent channel D/U ratios at all points within the service area of a television station would require that cellular transmissions on the same and adjacent channels be excluded from an area somewhat larger than the television service area. Cellular mobiles and portables transmit relatively low power, but can produce high field strengths at short distances. Therefore, a cellular transmitter operating on one of the affected channels within the television service area would create a zone of potential interference within which the D/U ratio would be less than the minimum allowed.[27] Further, to maintain the D/U ratio at the edge of the television service area would require that cellular mobiles be excluded within an additional setback distance. A specific setback would not be required for cellular base stations which could maintain required D/U ratios by using directional antennas and pointing them away from the protected contour.

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[25] Of the various taboos, image interference is probably of greatest concern. Image interference to a television station can be caused by other uses 14 and 15 channels above the channel used by the TV station, i.e., on channels N+14 and N+15. If the other use is another TV station, current rules require separations of 74.5 miles for channel N+15 and 59.5 miles for channel N+14. However, land mobile, including existing cellular, is now permitted immediately above the UHF TV band and, despite the potential for image interference to stations on channels 54 through 69, no distance separation is required. To our knowledge, this arrangement has not resulted in significant interference.

[26] The term dB (abbreviation for decibel) is used to express the relative strength of two signals on a logarithmic scale. If P1 is the power in one signal and P2 the power in another signal, their relative strength in dB is equal to 10 log P1/P2. The strength of radio signals (i.e., field strength) is normally expressed in volts per meter rather than power. Because power is proportional to the square of voltage, a D/U ratio is equal to 20 log Vd/Vu where Vd is the field strength of the desired signal and Vu the strength of the undesired signal. Thus, a D/U ratio of 50 dB equates to a desired field strength 316 times greater than that of the undesired signal. Similarly, a 0 dB ratio indicates field strengths of equal magnitude.

[27] The size of the interference zone would be inversely proportional to the strength of the TV signal. The zone would therefore be larger if the cellular transmitter were near the fringe of the TV service area than if it were located near the TV station.

Current land mobile sharing is based on maintaining D/U ratios at a television station's 64 dBu, or "grade B", field strength contour.[28] Thus, the maximum cellular field strength that could be permitted at this contour would be 64 - 50 = 14 dBu in the co-channel case and 64 - 0 = 64 dBu in the adjacent channel case, and the mobile setback distances in the two cases would be the distance from the mobile transmitter to its 14 dBu and 64 dBu field strength contours.

To calculate these distances, a mobile power and antenna height must be assumed. Current cellular mobiles are permitted to radiate up to 7 watts of power. In this study, we assumed a 7 watt mobile operating at an antenna height of 100 feet above average terrain. This is conservative, since most cellular mobiles operating with 7 watts of power are likely to be installed in vehicles operating at street level. Using these assumed mobile parameters and the FCC's propagation curves, the distances to the cellular mobile's 14 dBu and 64 dBu field strength contours are 29 miles and 1.5 miles, respectively.[29] These are the mobile setbacks needed to maintain the required D/U ratios at the television station's grade B contour.

These mobile setback distances must be added to the television station's grade B service area to define the area precluded to cellular. The size and shape of a television station's service area will vary depending on the actual radiated power and antenna elevation above average terrain in different directions around the transmitter. While it would be important to account for these variables in designing actual cellular systems for operation in this spectrum, they are less important in a concept study such as this. Consequently, to keep our calculations manageable, we modeled all full power television stations and vacant allotments as omnidirectional transmitters radiating the maximum allowable power of 5 million watts at the 2000 foot maximum antenna height permitted for that power.[30] Applying these idealized maximum parameters to the FCC propagation curves produces a circular grade B contour 66.5 miles in

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[28] The term dBu means dB relative to a field strength of 1 microvolt (millionth of a volt) per meter. A field strength contour is the locus of points around a transmitter at which the field strength is of constant magnitude. FCC rules classify a television station's grade of service according to field strength contours. The 64 dBu contour is referred to as the station's grade B service contour and is generally considered to define the area within which the station provides a reliable grade of service which should be protected from interference. See 47 CFR 73.683.

[29] The F(50,10) propagation curves in 47 CFR 73.699, Figure 10c, are generally used to calculate the field strength of interfering stations (in this case the cellular mobile) and the F(50,50) curves in Figure 10b, for the protected stations. See note 135 in appendix A for an explanation of the difference between these curves.

[30] In the UHF band, the maximum permissible effective radiated power (ERP) is 5 million watts. This maximum power may be used with an antenna height above average terrain (HAAT) of up to 2000 feet. At higher antenna heights, radiated power must be reduced according to a formula which keeps the distance to the grade B service contour approximately constant. See 47CFR 73.614.

radius. Including the setback distances, the radius precluded to cellular would therefore be 66.5 + 29 = 95.5 miles in the co-channel case and 66.5 + 1.5 = 68 miles on the two adjacent channels.

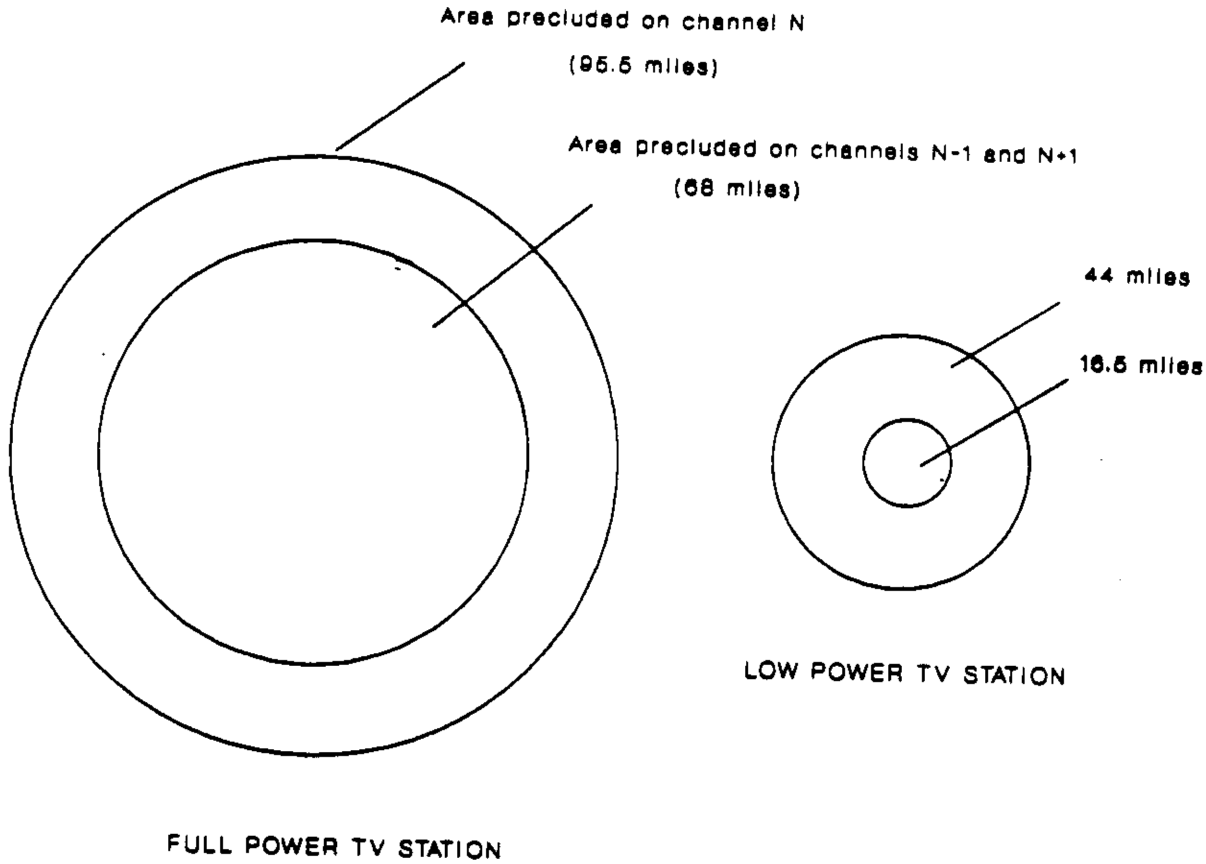

Figure 1: Potential cellular spectrum precluded by a UHF TV station on channel N.

Cellular spectrum precluded by a full power television assignment on channel N according to this model is depicted in the drawing on the left side of figure 1. The other drawing in the figure shows the corresponding areas precluded by a low power television station with an assumed service radius of 15 miles and using the same mobile setbacks.[31] The large circle in each of these drawings represents the area precluded on channel N, i.e., the co- channel area, and the smaller circle is the area precluded on the two adjacent channels N-1 and N+1.

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[31] Since FCC rules do not specify a maximum radiated power and antenna height for low power stations, a maximum service radius could not be determined as was done for full power allotments. However, according to Commission personnel involved in the licensing of low power stations, the grade B contours of such stations rarely extend beyond 15 miles even with the use of directional antennas with non-circular coverage. Therefore, we make the conservative assumption that all low power stations have a circular service area 15 miles in radius. Adding in the mobile setbacks derived in the preceding paragraph results in a co-channel precluded area 44 miles in radius and an adjacent channel area 16.5 miles in radius.

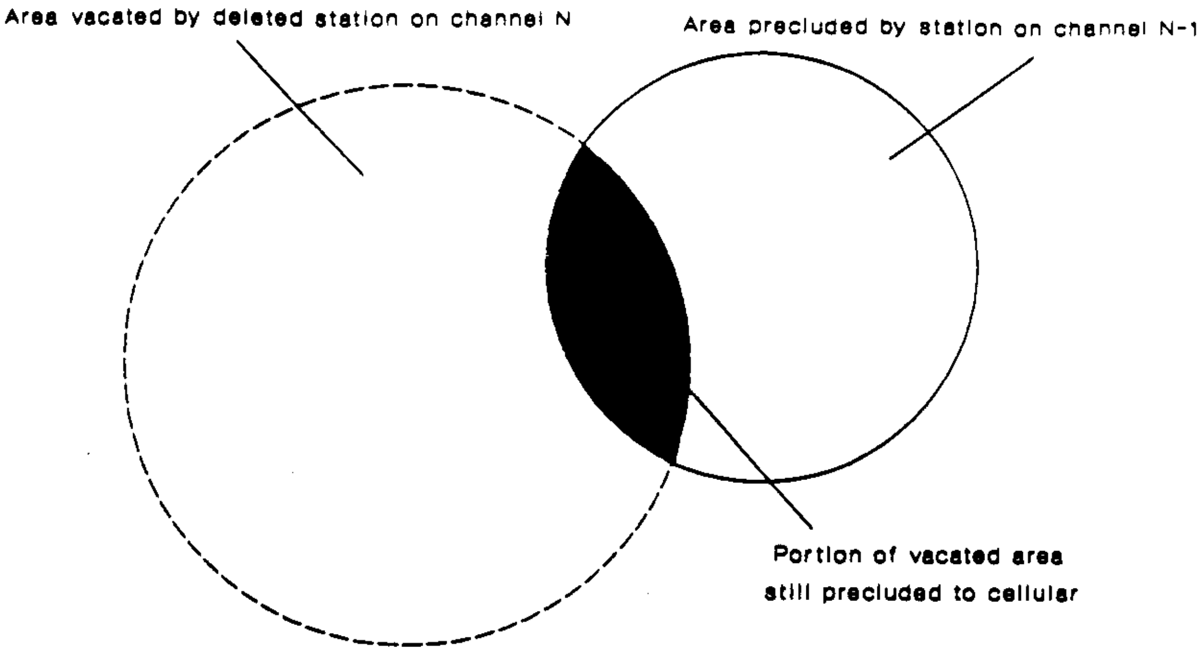


Figure 2: Area freed for cellular use on channel N reduced by a nearby TV station on channel N-1.

Assuming there were no other nearby stations, the circles in figure 1 represent the areas where these channels would be freed for cellular use by removing the channel N assignment or vacant allotment. However, in most actual situations some of this spectrum would continue to be precluded by other stations in the area. This effect is illustrated in figure 2. In this figure, only the precluded area on channel N is shown. The dashed circle in the middle represents the 95.5 mile area that had been precluded by a co- channel full power assignment that has now been deleted. The solid circle represents area still precluded on channel N by a nearby assignment on adjacent channel N-1. The intersection of the two circles represents area vacated by the deleted assignment but still unavailable for cellular use. Because of this overlapping of precluded areas, the area where each channel (N, N-1 and N+1) is released by deleting an actual television assignment may be broken into several pieces of different size.

D. SUMMING RELEASED CELLULAR SPECTRUM

A procedure for summing released cellular spectrum must take into account this variation of bandwidth with location. Within a sufficiently small unit of area, say a square mile, it would be reasonable to assume that released bandwidth is constant. Each square mile of area would thus represent either zero, one, two or three square mile-channels of released spectrum and square mile-channels could be added over the entire area to produce a total. However, our purpose is not just to calculate the physical quantity of released cellular spectrum but also its value.

Cellular spectrum value in turn depends on demand, and cellular demand also varies with location. A square mile-channel of cellular spectrum would be less valuable in the desert or ocean than in the center of Los Angeles. This suggests that before physical square mile-channels of released spectrum are summed, each one should first be multiplied by a factor representing cellular demand within that particular square mile.

Fortunately, in the case of cellular there is a convenient measure of cellular demand that can be used in this calculation. Cellular systems are generally designed with an equal amount of spectrum per cell site, and, assuming that all cell sites in a system use basically the same technology, each site is also capable of providing an equal amount of cellular service. Since cell sites are expensive, they are added only in sufficient numbers to meet the expected demand over a relatively short period of time. Therefore, at any point in time, each existing cell site represents an approximately equal unit of current demand. Moreover, if future demand can be expected to grow proportionally to current demand, then an existing cell site also represents a unit of long term demand. In other words, the demand in the area covered by an existing cell site would remain a constant portion of total system demand at any point in the future. We believe this to be a reasonable assumption, since cellular traffic in an area will tend to track other geographical distributions that change relatively slowly, e.g. population, business activity, income levels and highway infrastructure.

If we multiply each square mile-channel of physical spectrum by the number of existing cell sites in that square mile, we are left with site-channels as the relevant economic measure of released spectrum and the troublesome area dimension disappears altogether. In section VI, we calculate the incremental value of one, two or three channels (6, 12 or 18 MHz) of additional cellular bandwidth in the Los Angeles cellular market. Again, if we accept that each existing cell site represents a unit of demand, these market wide incremental spectrum values can be expressed on a per cell site basis by dividing by the number of existing cell sites in the area. Using these per cell site spectrum values, the total value of the spectrum released by deleting a television station can be calculated as follows: 1) determine the number of channels of bandwidth released at each of the existing cell sites in the area; 2) assign one of the derived per cell site incremental spectrum values to each existing cell site according to the amount of bandwidth released at that site; and 3) sum these per site values over all of the cell sites in the area. In the remainder of this section we are concerned only with step 1 of this procedure. The value calculations are presented in sections V and VI.

E. ANALYSIS OF THE LOS ANGELES AREA

As indicated, our specific interest was not just to define the area where spectrum is released, but to count how many channels (zero, one, two, or three) would be released at existing cell sites within a 104.5 mile radius of Los Angeles by individually deleting each of the 13 assignments within a 40 mile radius of Los Angeles. A computer program was written to assist in this analysis.

To analyze cellular spectrum availability in the Los Angeles area, we constructed a database consisting of all existing and proposed uses of the UHF band within a 200 mile radius centered on Los Angeles. This database allows for the calculation of cellular spectrum availability within a smaller, 104.5 mile radius, defined by subtracting the radius (95.5 miles) precluded to cellular by a co-channel, full power television assignment from the 200 mile database limit. By confining our calculations of cellular spectrum to this 104.5 mile circle, we can be certain that our database contains all uses that could receive interference from cellular. Existing wireline system cell sites within the 104.5 mile circle were also included in the database to serve as the reference points for spectrum calculations. The 104.5 mile circle includes most of the Los Angeles cellular franchise area plus portions of surrounding areas.

The deletion of any full power UHF assignment or vacant allotment within the 200 mile radius could potentially release some amount of cellular spectrum at locations inside the 104.5 mile circle. However, the more distant a station is from the center of the city, the more likely it is that significant portions of the released spectrum will occur outside the Los Angeles cellular market, which is the area of interest in this study. It is for this reason that we limited our analysis to the 13 assignments within 40 miles of Los Angeles. Even with this limitation, there will be some undercounting of released cellular spectrum since a deleted assignment 40 miles out could free cellular spectrum at distances as great as 40 + 95.5 = 135.5 miles from the center of the city.

The following UHF uses were included in our database: all existing full power assignments and vacant allotments; all low power TV stations; all existing and proposed land mobile sharing channels; the channel 37 radioastronomy channel; and the hypothetical group of UHF ATV allotments discussed above. Mexican television stations and vacant allotments within 200 miles of Los Angeles were also added to the database, but were analyzed separately. The uses included in our database are listed in appendix C.

One of the outputs of the computer program is a map showing cellular spectrum availability within the 104.5 mile circle over a block of any three contiguous channels corresponding to an assigned (or allotted but vacant) NTSC channel and the two adjacent channels. The map is shaded to show areas where zero, one, two or three of these channels (0, 6, 12 or 18 MHz) are technically available for cellular use based on our interference model. The existing wireline cell sites used as reference points are also plotted. Comparing maps drawn before and after the deletion of a specified assignment gives a visual indication of the resulting increase in cellular spectrum availability.

Sample maps drawn by the program are presented in figures 3 and 4, showing the effect of deleting NTSC assignments on channels 52 and 34, respectively. The maps at the top and bottom of each figure show cellular spectrum availability before and after deletion of the assignment. The maps on the left correspond to policy scenario 1 (existing and proposed uses protected) and on the right to scenario 2 (existing uses protected). The large circle in the center of each map with crosses every 90 degrees around its circumference is the 104.5 mile target area. Shading inside this circle indicates the number of TV channels available at different locations throughout the area, and the small crosses (dots) represent the wireline cell sites.

The numbers scattered across the maps are channels assigned to the various UHF uses that preclude cellular operation on one or more of the three channels shown on the map. Each such use is represented by a circle for each of the three channels that it affects: full power and low power NTSC stations and vacant allotments appear as depicted in figure 1; ATV allotments appear as a 95.5 mile circle on the allotted channel only, since we have assumed that ATV allotments will require only co-channel protection; and land mobile channels appear as 104.5 mile circles centered on Los Angeles, indicating that the channel is unavailable for cellular use throughout the area.

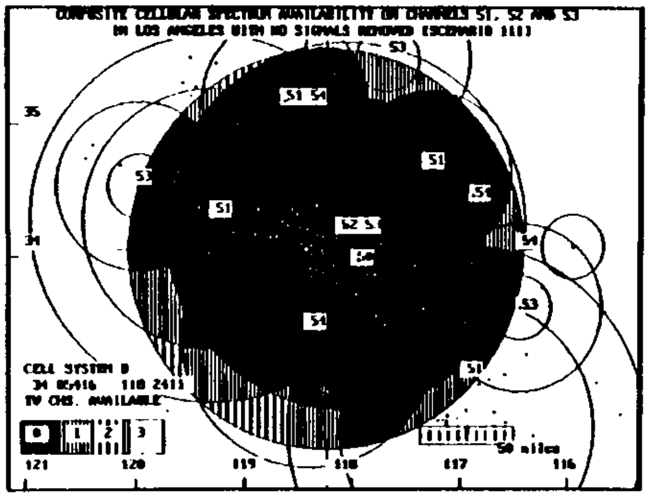
Notice in the top maps in figures 3 and 4 that the most important central portion of the study area is shaded black, indicating zero spectrum availability on the three channels before the television assignment is deleted. In both figures, deletion of the assignment (bottom maps) results in some release of cellular spectrum in this central area, but the amount released is much greater for channel 34 than for channel 52, under either scenario. The largest increase in spectrum availability occurs with the deletion of channel 34 under scenario 2 (only existing uses protected), which nets 18 megahertz over most of the central area. Under scenario 1, the yield from the channel 34 deletion in roughly this same area is reduced to 12 megahertz because of a nearby ATV allotment on channel 35.

In addition to the maps, the program also counts the number of existing cell sites in the 104.5 mile circle having 0, 1, 2 or 3 channels (0, 6, 12 or 18 MHz) available before and after the deletion of a specified NTSC assignment or vacant allotment. Sample results of this analysis for the same two assignments (channels 52 and 34) are presented in a somewhat different perspective in figure 5. The bars on this chart represent cellular spectrum availability on each

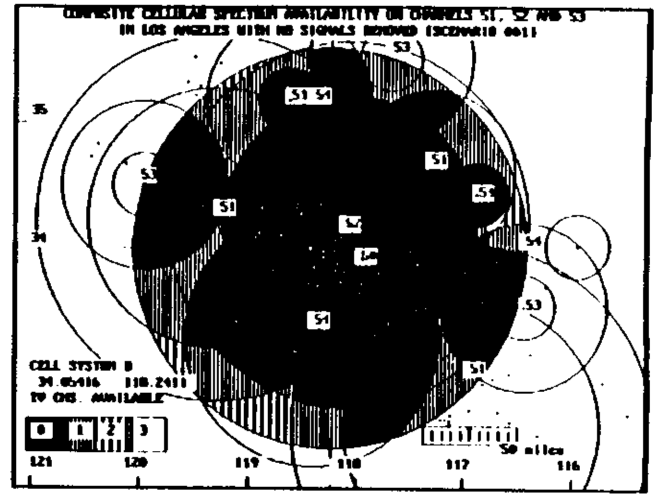
Figure 3

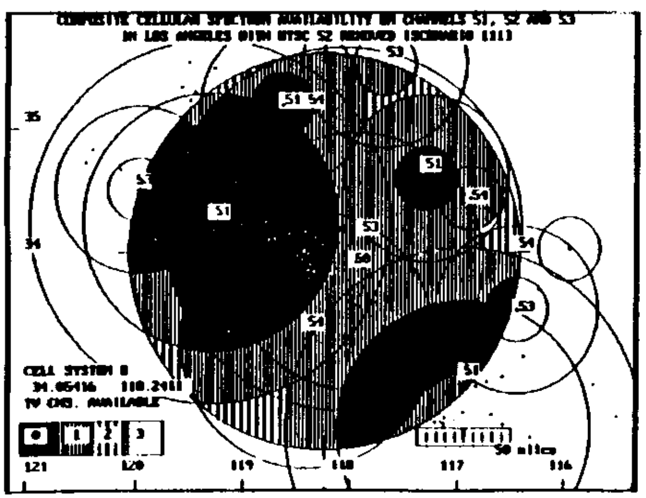
CELLULAR SPECTRUM ON CHANNELS 51, 52 AND 53 AT WIRELINE SYSTEM CELL SITES WITHIN 104.5 MILES OF LOS ANGELES WITH AND WITHOUT LOS ANGELES TELEVISION ASSIGNMENT ON CHANNEL 52

Scenario 1 (Existing and Proposed Uses Protected)		Scenario 2 (Existing Uses Protected)



With channel 52





Without channel 52

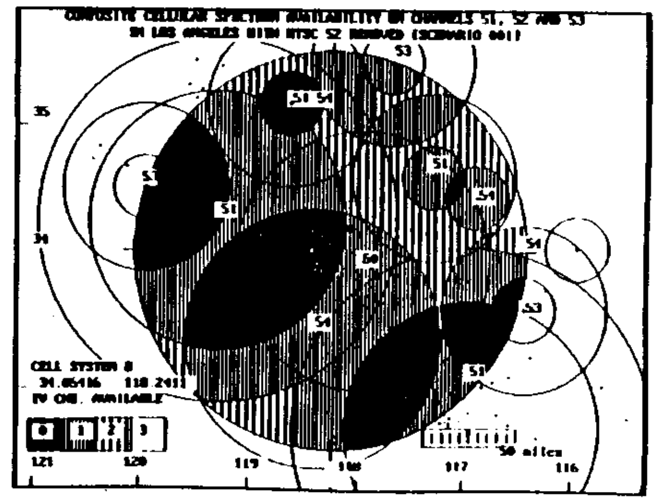


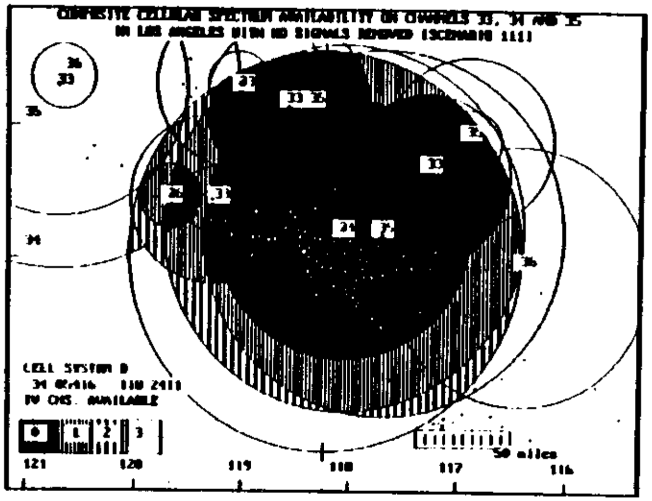
Figure 4

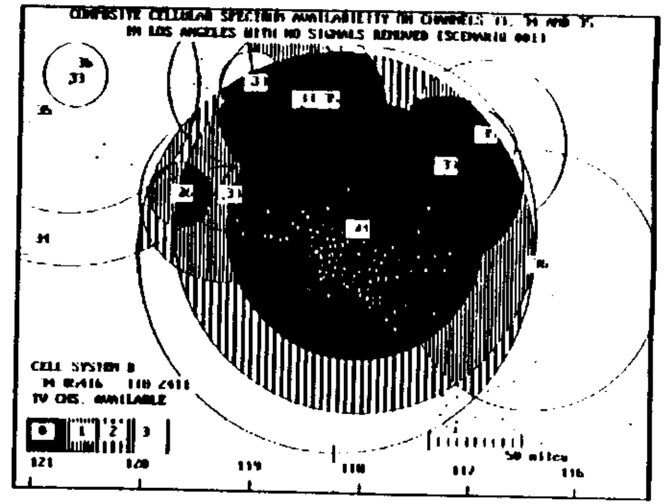
CELLULAR SPECTRUM ON CHANNELS 33, 34 AND 35 AT WIRELINE SYSTEM CELL SITES WITHIN 104.5 MILES OF LOS ANGELES WITH AND WITHOUT LOS ANGELES TELEVISION ASSIGNMENT ON CHANNEL 34

Scenario 1
(Existing and Proposed Uses Protected)

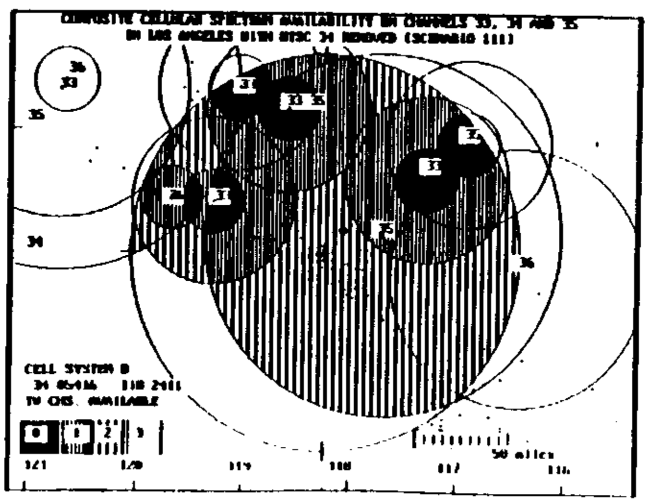
Scenario 2
(Existing Uses Protected)

With channel 34





Without channel 34



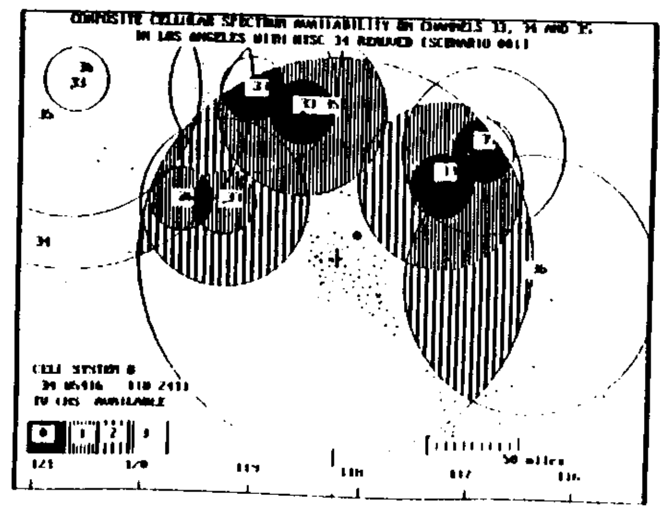
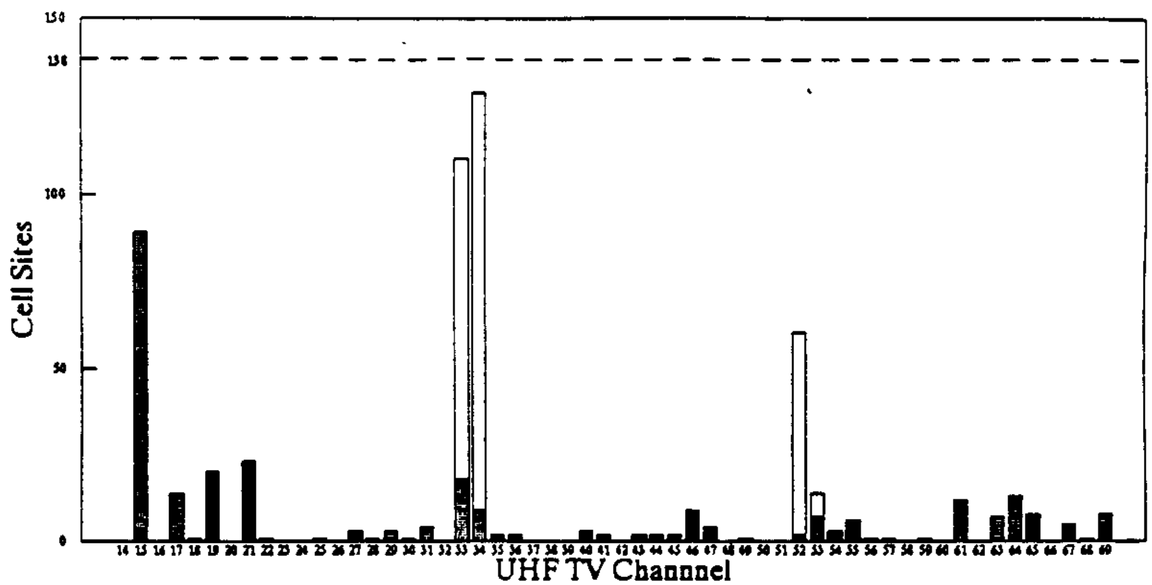


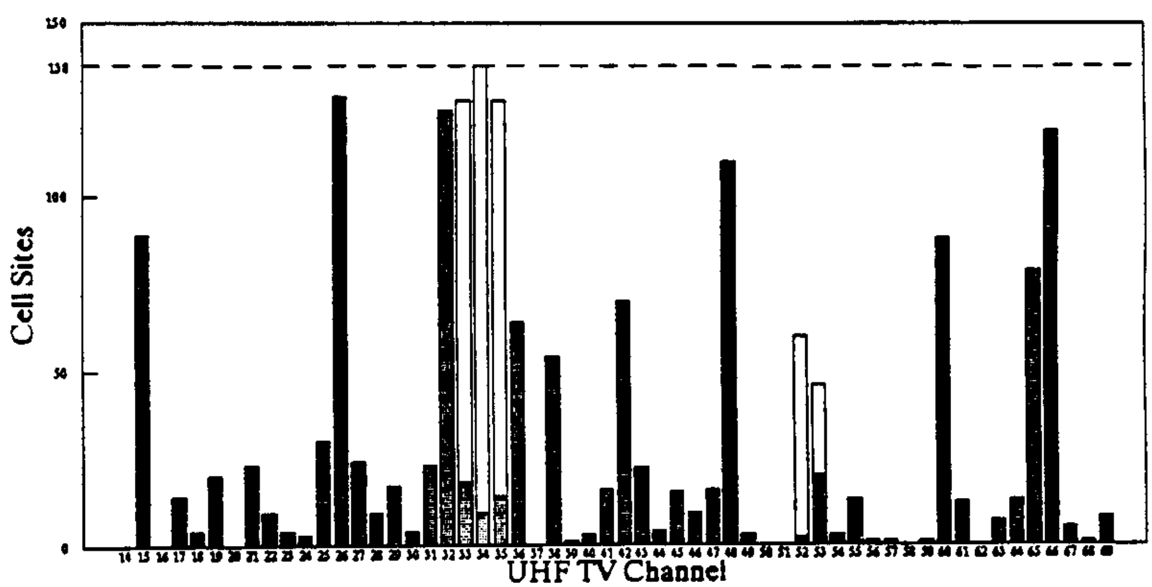
Figure 5

POTENTIAL CELLULAR SPECTRUM IN LOS ANGELES ON UHF CHANNELS 14–69
WITH ASSIGNMENTS ON CHANNELS 34 AND 52 DELETED

Scenario 1
(Existing and Proposed Uses Protected)



Scenario 2
(Existing Uses Protected)



NOTES:

1. Bar heights represent the number of wireline system cell sites within 104.5 miles of Los Angeles at which the indicated channel could be used for cellular without interfering with protected uses. There are 138 cell sites within the 104.5 mile circle.

2. The shaded parts of the bars indicate cell sites available with no television assignments removed, and the unshaded parts are the sites added by removing the indicated assignments.

3. Scenario 1 protects existing and proposed uses including hypothetical ATV channels and proposed land mobile sharing channels. Scenario 2 protects existing full power assignments and vacant allotments, existing low power assignments and existing land mobile channels.

of the 56 UHF channels based on our interference analysis. The height of each bar indicates the number of cell sites at which the channel is available, with the shaded portion indicating sites available before any assignments are deleted and the unshaded portion the increase in sites after the two assignments are deleted. The dashed line across the top of each chart indicates the 138 cell sites within the 104.5 mile circle and from the standpoint of cell sites represents 100 percent availability. The top chart in the figure shows the results under scenario 1 and the bottom chart for scenario 2.

The shaded bars in both of these charts represent what might be considered the residual cellular spectrum available in the band in Los Angeles under the two scenarios. This is spectrum that could be used for cellular without deleting any existing assignment or vacant allotment. As could be expected, the amount of residual cellular spectrum is much less if proposed as well as existing uses of the band are protected.[32]

To determine the maximum spectrum that could be made available by the deletion of any Los Angeles television assignment or vacant allotment, the analysis described above for channels 52 and 34 was done for all 13 assignments within 40 miles of Los Angeles. The results under the two scenarios are depicted in figure 6.[33] In this figure, each bar represents composite spectrum availability over the three affected channels after a particular assignment is deleted.[34] Shading of the bars indicates the number of cell sites having the indicated amounts of bandwidth.

As can be seen in figure 6, the amount of cellular spectrum available varies widely depending on which television assignment is deleted and on assumptions about the protection of other uses. Under scenario 1, which protects proposed as well as existing uses, eight of the deletions produce at least 6 MHz at more than half of the cell sites; four of those yield at least 12 MHz at over half of the sites and one of those provides 18 MHz at approximately half of the

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[32] Under scenario 1 assumptions, it appears that the only way to obtain a significant amount of cellular spectrum in this area in the UHF band under our assumed cellular technology and interference model would be to delete an existing NTSC assignment or other protected use.

[33] A version of figure 6 including Mexican television assignments and vacant allotments is presented in appendix D. In that figure, the same protection is assumed for both the Mexican and U.S. assignments. As can be seen by comparing figure 6 with appendix D, including the Mexican usage causes some reduction in cellular spectrum availability in the Los Angeles area. However, the reduction would be less if those portions of the Mexican station grade B contours within the U.S. are not protected.

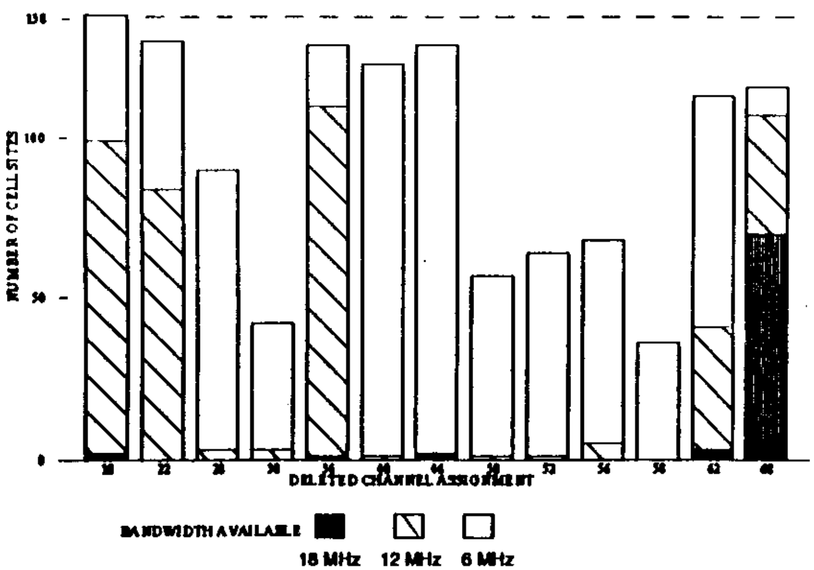
[34] These graphs do not subtract out the residual spectrum available before the assignment is deleted as shown in the preceding figure on the assumption that such spectrum would probably not be usable for cellular unless the assignment is deleted.

FIGURE 6

FREQUENCY BANDWIDTH TECHNICALLY USABLE FOR CELLULAR SERVICE AT WIRELINE SYSTEM CELL SITES WITHIN 104.5 MILES OF LOS ANGELES AFTER THE DELETION OF INDIVIDUAL UHF TELEVISION ASSIGNMENTS WITHIN 40 MILES OF LOS ANGELES

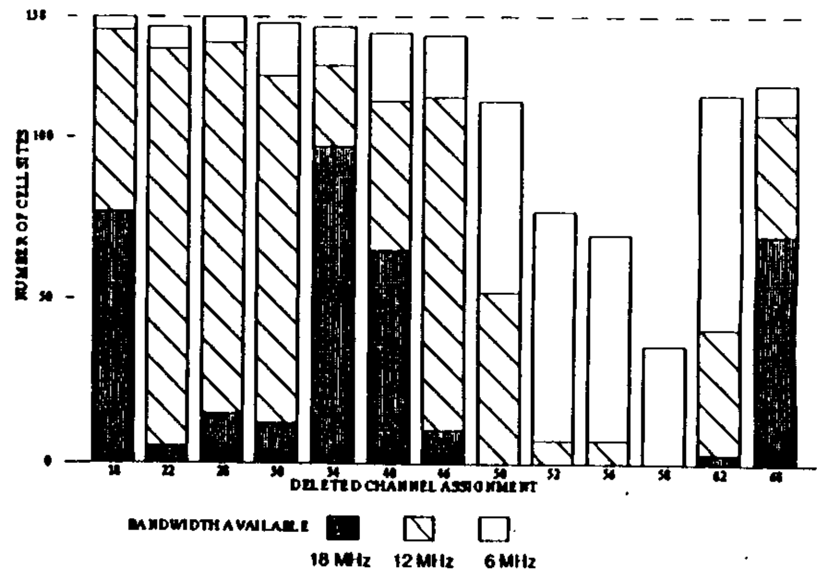
Scenario 1
(Existing and Proposed Uses Protected)

BANDWIDTH AVAILABLE	NUMBER OF CELL SITES HAVING THIS AMOUNT OF BANDWIDTH AVAILABLE AFTER DELETION OF ASSIGNMENT ON CHANNEL:												
AT SITE	18	22	28	30	34	40	46	50	52	56	58	62	68
0 MHZ	0	8	48	96	9	15	9	81	74	70	102	25	22
6 MHZ	39	46	87	39	19	122	127	56	63	63	36	72	9
12 MHZ	97	84	3	3	109	1	0	1	1	5	0	38	37
18 MHZ	2	0	0	0	1	0	2	0	0	0	0	3	70



Scenario 2
(Existing Uses Protected)

BANDWIDTH AVAILABLE	NUMBER OF CELL SITES HAVING THIS AMOUNT OF BANDWIDTH AVAILABLE AFTER DELETION OF ASSIGNMENT ON CHANNEL:												
AT SITE	18	22	28	30	34	40	46	50	52	56	58	62	68
0 MHZ	0	4	1	3	4	6	7	27	61	68	102	25	22
6 MHZ	5	7	8	16	12	21	19	59	70	63	36	72	9
12 MHZ	56	122	114	107	25	46	102	52	7	7	0	38	37
18 MHZ	77	5	15	12	97	65	10	0	0	0	0	3	70



NOTES:

1. Each bar represents the column of data directly above it.
2. There are 138 wireline system cell sites within the 104.5 mile study radius.
3. Scenario 1 assumes protection of existing full power television assignments and vacant allotments, existing low power assignments, current and proposed land mobile sharing channels, and the hypothetical ATV allotments.
4. Scenario 2 assumes protection of existing full power television assignments, and vacant allotments, existing low power assignments and current land mobile sharing channels.

sites.[35] Under scenario 2, where the assumption is that only existing uses would be protected, ten of the thirteen possible deletions would release at least 6 MHz at nearly all sites; eight of those would release at least 12 MHz at nearly all sites; and three of those would release 18 MHz at least half of the sites. The exact numbers are given in the tables directly above the bar graphs. The value of this released cellular spectrum is calculated in sections V and VI.

[35] This would be more than half the number of sites in the Los Angeles wireline system since our 104.5 mile study area contained more sites than existed in the Los Angeles system at that time. See note 10, supra.

IV. VALUE OF SPECTRUM USED IN TV BROADCASTING

A. BACKGROUND

1. A Channel is a Channel

In evaluating both the social and the private consequences of taking a UHF TV channel off the air it is important to note that the loss of a channel is not equivalent to the loss of the programming and advertising that was provided on that channel. When a TV station discontinues broadcasting, some programming on that channel, including local news and public affairs, may be picked up by remaining channels, displacing other programming that has less value to advertisers. Thus the loss to consumers and advertisers is the loss in value of the programming that is ultimately displaced, not the programming that was on the channel that is shut down. We will therefore assume that all channels with the same geographic coverage have the same value to viewers and advertisers.[36]

Thus, we assume that the lowest trading price of UHF TV stations with equivalent geographic coverage -- minus the salvage value of the physical assets of such stations -- is a reasonable estimate of the minimum amount a broadcaster would accept for the use of his spectrum. Since the typical salvage value of these physical assets is under a million dollars, we ignore this factor in our calculations.[37]

As a practical matter we must base our estimates of UHF spectrum values on a very limited number of station sales. As shown in table 1, the most recent transaction in Los Angeles was in 1986 for $35 million, and the next most recent was in 1985 for $30 million.

If, as discussed above, migration of programming occurs, a precise analysis would take into account its costs. Switching programming among channels would involve certain expenses that depend on the number of programs moved. For our analysis, however, we will not consider these costs.

2. The Los Angeles Market

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[36] This does not imply, however, that only the socially least valuable programming would be lost. As the analysis in section II implies, the least valuable programming in the marketplace may not be the socially least valuable programming. See Spence and Owen, "Television Programming, Monopolistic Competition, and Welfare, Quarterly Journal of Economics, 91(Feb. 1977), 103-127. They argue that the market may fail to provide the welfare maximizing mix of programming.

[37] FCC, Mass Media Bureau estimate, 1988.

The social loss from discontinuing TV service on a UHF channel depends in large part on the number of potential viewers. Approximately 4.55 million households can receive the signal of a typical full power UHF station broadcasting over downtown Los Angeles.[38]

The loss also depends on the number of households who subscribe to cable and hence are unlikely to rely on broadcasting for TV service. About 1.66 million cable subscribers are within the coverage area of UHF TV stations serving downtown Los Angeles.[39] This implies that there are 2.89 million households who can receive the signal, but who do not subscribe to cable. We assume that the loss from discontinuing broadcasting would be concentrated on these households.

Table 2 compares cable penetration in Los Angeles and the U.S. as a whole, showing that in 1988 only 45 percent of the homes passed in Los Angeles subscribed, while nationwide the number was 66 percent. An important factor explaining the low cable penetration rate in Los Angeles is the high number of stations available over the air.[40] Altogether, sixteen channels are available over the air in Los Angeles, including three stations affiliated with the major networks (ABC, NBC, and CBS), a Fox network affiliate, a Trinity Broadcasting Network affiliate, two affiliates of Spanish-language networks (Telemundo and Univision), two PBS stations, and two stations carrying Home Shopping Network programs.[41]

To evaluate the social value of using spectrum to provide a UHF TV channel it is necessary to project the growth in the number of television households, homes passed by cable, and homes subscribing to cable. Such projections are needed because any optimal reallocation is likely to last for an extended time period given the large sunk costs of putting spectrum to a new use. We began our analysis with 1992 because it is unlikely that spectrum could be

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[38] This is our estimate of the number of television households within the grade B contour of a typical UHF TV station covering downtown Los Angeles. All stations serving the downtown area have approximately the same grade B contour. The estimated number of television households is based on January 1989 county and sub-county data supplied by Arbitron Ratings Company. We chose the following counties and partial counties as an approximation of the area within the grade B contour: Los Angeles, Orange, Riverside West Inner, Riverside West Outer, San Bernardino West Inner, San Bernardino West Outer, and Ventura East.

[39] We estimated the number of cable subscribers and the number of televisions households passed by cable in 1988 using a Los Angeles cable map supplied by the Southern California Cable Association. First, we determined which cable systems were within the grade B contour of a typical station serving downtown Los Angeles. Then we totaled the homes passed and subscribers for all of the 77 cable systems within that contour.

[40] Noll, Peck, and McGowan (pp.289-299) found that the number of stations available over the air was an important determinant of cable penetration in the largest 100 markets.

[41] Television and Cable Factbook, 1989 ed. (Washington, D.C.: Warren Publishing, Inc., 1989); TV Guide, Los Angeles Metro Edition, (Radnor, PA: News America Publications Inc., July 15, 1989).

Table 2: Television and Cable Penetration in Los Angeles and the U.S

	Los Angeles*	U.S.**	
	1988	1988	1990
Total TV Households (TVHH)	4.55	90.4	92.1
Homes Passed by Cable (millions)	3.68	73.9	73.9
% TVHH Passed by Cable	80.9%	81.7%	80.2%
Homes Subscribing to Cable (millions)	1.66	48.6	53.2
% Homes Passed Subscribing	45.1%	65.8%	72.0%
% Total TVHH Subscribing	36.5%	53.8%	57.8%

NOTES:

* Total television households in Los Angeles were estimated using January 1989 Arbitron data. Homes passed and homes subscribing in Los Angeles were estimated using a cable map of Los Angeles supplied by the Southern California Cable Association and were for households within the grade B contour of channel 34.

** U.S. data for 1988 comes from Broadcasting, January 2, 1989, p.16. U.S. data for 1990 is from Broadcasting, May 21, 1990, p.14.

switched from UHF TV to cellular telephone any sooner,given the necessary regulatory actions and the time needed to design and construct a cellular system to use this spectrum. Detailed analysis was carried out only to the year 2000 because of the difficulty in projecting events beyond that point.

We assumed that the number of television households in Los Angeles will grow at 1.5% per year through the year 2000.[42] We also assumed that throughout the period 1992-2000 90% of households will be passed by cable.[43]Finally, we assumed that the percentage of homes passed that subscribe to cable will increase two percentage points per year from 1988 to 2000. Under these assumptions, cable subscription rates for homes passed in Los Angeles will reach the 1990 national rate of 72% in mid-1999.

[42] We assumed that population in Los Angeles will not continue to grow at the rate experienced during the 1980's, but will slow down to approximately the rate prevailing during the 1970's. Between 1970 and 1980 population in the Los Angeles CMSA grew at annual rate of 1.4%. It increased to an annual rate of 2.2% between 1980 and 1987. During both periods it exceeded the average rate of growth in all U.S. metropolitan areas of 1% for 1970-1980 and 1.1% for 1980-1987. (U.S. Bureau of the Census, Statistical Abstract of the U.S.: 1989 (109th edition), Washington, DC. 1988, pp. 28,30).

[43] This estimate was provided by Mike Morris of the Southern California Cable Association (and now Continental Cablevision) in a 1989 conversation with the authors.

B. VALUING THE LOSS OF A TV CHANNEL

1. Market Value

The market value of spectrum used to provide a UHF TV broadcast signal to downtown Los Angeles for the years 1992 to 2000 is shown in table 3. The estimated annual after-tax profits of $3.5 million for a UHF TV station covering downtown Los Angeles was calculated as one tenth of the 1986 trading price of station KHSC (see table 1), the most recently sold UHF TV station covering downtown Los Angeles.[44] We based the ratio of annual profits to trading price on an assumed 10% discount rate, which implies that an infinitely lived asset will provide an annual after-tax return of 10% of its price.[45]

Ignoring the scrap value of the station's physical assets and the value of any "good will" that could be transferred to another station, the present discounted value of these after-tax profits from 1992 to 2000 -- $20.2 million -- is an estimate of the amount a broadcaster would have to be paid at the end of 1991 to give up the use of a UHF TV channel in downtown Los Angeles for the years 1992-2000. We will refer to this as the market value of spectrum used in UHF TV broadcasting in Los Angeles. Since it is based on only a nine year period, it is less than the observed station trading price of $35 million, which reflects the stream of profits for the entire expected life of a station.

2. Social Value

Our measure of the social value of spectrum in providing TV service is the change in consumer plus producer surplus from discontinuing broadcasting on that spectrum. Consumer surplus is the amount that consumers would be willing to pay for a good or service beyond the amount they actually pay. Since consumers do not pay to receive an over-the-air signal, consumer surplus equals the total benefit to viewers from receiving the signal.Producer surplus is the broadcaster's before-tax profits. Assuming that a broadcaster's advertising revenue measures the benefits of advertising to advertisers, and that advertising is the sole source of revenue for a broadcaster, producer surplus is equivalent to the value of the benefits to advertisers

[44] Using the most recently traded station tends to overestimate the value of spectrum used in UHF TV broadcasting, since there is no reason to believe that this station is the least valuable one, which, as we discussed in the section "A channel is a channel," is what should be used.

[45] The post-war ratio of corporate profits, after corporate income taxes, to stockholders' equity has ranged between approximately 10% and 15%. See, Council of Economic Advisers, Economic Report of the President (Washington, D.C.: Government Printing Office, 1988), Table B-91, p. 353.

Table 3

SOCIAL AND MARKET VALUE OF SPECTRUM USED TO PROVIDE A UHF TV BROADCAST SIGNAL TO DOWNTOWN LOS ANGELES 1992-2000

Year

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
TV AND CABLE MARKET DATA										
TV Households (millions)	4.76	4.83	4.90	4.98	5.05	5.13	5.20	5.28	5.36	5.44
Percent TVHH Passed	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
Homes Passed (millions)	4.28	4.35	4.41	4.48	4.55	4.62	4.68	4.75	4.83	4.90
Percent HP Subscribing	55.0%	57.0%	59.0%	61.0%	63.0%	65.0%	67.0%	69.0%	71.0%	73.0%
Subscribers (millions)	2.36	2.48	2.60	2.73	2.86	3.00	3.14	3.28	3.43	3.58
Percent TVHH Subscribing	49.5%	51.3%	53.1%	54.9%	56.7%	58.5%	60.3%	62.1%	63.9%	65.7%
TVHH Not Subscribing (m)	2.40	2.35	2.30	2.24	2.19	2.13	2.07	2.00	1.94	1.87
MARKET VALUE										
Station Profits After Taxes ($m)		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Present Value After-tax Profits	20.2									
PRODUCER SURPLUS										
Station Profits Before Taxes ($m)		5.47	5.47	5.47	5.47	5.47	5.47	5.47	5.47	5.47
Present Value Before-tax Profits	31.5									
CONSUMER SURPLUS										
TVHH Not Passed										
Number of households (m)		0.48	0.49	0.50	0.51	0.51	0.52	0.53	0.54	0.54
Annual value per household ($)		20.49	20.49	20.49	20.49	20.49	20.49	20.49	20.49	20.49
Total annual value ($ m)		9.90	10.05	10.20	10.35	10.51	10.66	10.82	10.99	11.15
Present value ($ m)	59.99									
TVHH Passed But Not Subscribing										
Number of households (m)		1.87	1.81	1.75	1.68	1.62	1.55	1.47	1.40	1.32
Annual value per household ($)		5.98	5.67	5.35	5.05	4.74	4.41	4.12	3.83	3.54
Total annual value ($ m)		11.18	10.26	9.35	8.50	7.66	6.82	6.07	5.36	4.68
Present value ($ m)	47.67									
SOCIAL VALUE (CONSUMER PLUS PRODUCER SURPLUS)										
Annual Social Value ($m)		26.55	25.78	25.01	24.32	23.63	22.95	22.37	21.82	21.30
Present value social value ($ m)	139.2									

minus the (non-spectrum) costs of providing the broadcasting service.[46]

Since benefits and costs accrue over time, to compare them they must be discounted to a common point in time. For simplicity we decided to use a common discount rate, 10%, for evaluating both market and social values.There is no universally accepted discount rate for calculating the latter.Three that have been proposed are (1) the before-tax interest rate on private investment, (2) a weighted average of the after-tax interest rate on private saving and the before-tax rate, and (3) the optimal social discount rate derived from theoretical models of economic growth.[47]

a. Producer surplus (value to advertisers minus costs). The before-tax profits of a UHF TV station covering downtown Los Angeles are shown in table 3 under the heading "producer surplus." On an annual basis they equal $5.47 million, with a present value of $31.5 million. They were calculated assuming an overall tax rate of 36% on profits, and were derived by solving for the numbers which when multiplied by the 64% share of profits retained by the broadcaster gives our estimated after-tax profits.

b. Consumer surplus (value to over-the-air TV viewers). In estimating the value of an over-the-air video channel, we distinguished between consumers who subscribe to cable and those who do not. For those viewers subscribing to cable, we assumed that there would be no loss if a station discontinued broadcasting. For those households that do not subscribe, we used a model developed by Noll, Peck, and McGowan to estimate the loss to viewers of taking a channel off the air, given the initial number of channels available over the air.[48]

By analyzing cable penetration, Noll, Peck, and McGowan (N-P-M) were able to estimate the amount that households are willing to pay for additional television channels. Their analysis is based on the idea that for those households who are just indifferent between subscribing to cable and not subscribing, the cable subscription fee measures the maximum amount that they would be willing to pay for the additional channels. One can use their estimates of the value of cable channels to infer the amount consumers would be willing to pay for over-the-air channels.

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[46] For a good brief introduction to welfare economics and the rationale for using consumer plus producer surplus as a measure of welfare see Steven Brown and David Sibley, The Theory of Public Utility Pricing (New York: Cambridge University Press, 1986), pp. 6-25. For a more rigorous discussion of the welfare economics of consumer surplus see R.D. Willig, "Consumer's Surplus Without Apology," American Economic Review 66, 1976, pp. 589-97.

[47] See Edward Gramlich, Benefit-Cost Analysis of Government Programs (Englewood Cliffs, N.J.: Prentice-Hall, 1981), pp. 95-108.

[48] Roger Noll, Merton Peck, and John McGowan, Economic Aspects of Television Regulation (Washington, D.C.: The Brookings Institution, 1973), Appendix B.

In principle, channels available over the air can be treated as equivalent to a cable system offering the same channels at a zero price.[49] This equivalence can be exploited in practice because the N-P-M analysis was done at a time when there were no premium cable channels, and cable was used almost exclusively to retransmit advertiser supported programming that was available over the air locally or in other cities.

To use the N-P-M model to estimate the amount that an average household would be willing to pay to avoid the loss of a TV channel, one must specify both the type and number of stations that can be received initially. N-P-M divided stations into two categories: affiliated and independent. Affiliated stations were those associated with one of the three major networks.[50] We treated the Los Angeles market as having four affiliated stations and twelve independents.

The N-P-M analysis can be applied directly to households not passed by cable since this group is likely to be representative of the entire population of potential viewers, and the N-P-M methodology assumed such a group. Using the N-P-M model we calculated that an average household would be willing to pay about 0.066% of its income to avoid the loss of one independent station.[51] Applying this to a median family income of $30,853 provides an annual loss in consumer surplus of $20.49 per household.[52]Multiplying the annual value per household by the number of households not passed by cable provides the total annual loss for this group. We calculated this to be $9.9 million in 1992, given our forecast that 480,000 households in Los Angeles will not be passed by cable at that time. The annual loss increases gradually as the population grows in areas not passed by cable. The present discounted value in 1991 of the annual losses for the years 1992 to 2000 is $59.99 million.

For households that are passed by cable but choose not to subscribe,the N-P-M model needs to be modified.[53] The fact that these households choose not to subscribe suggests that, on average, they place a lower value on additional channels than the population as a whole. The

[49] One possible qualification is that cable may provide better signal quality, but the N-P-M model takes this into account (p. 283).

[50] N-P-M also took into account three other types of channels in their econometric model through the use of dummy variables: (1) continuous broadcast of news, time, and weather, (2) programming originated by the cable system, and (3) educational television beyond what was available over the air (p. 284).

[51] See Appendix B.

[52] Lacking data on the median household income in Los Angeles, we used the 1987 national median family income. Council of Economic Advisers, Economic Report of the President, 1989, p. 342.

[53] We show these modifications in Appendix B.

N-P-M model ranks households according to the maximum amount they would pay for the additional channels offered by cable. Only those who are willing to pay more than the cable fee will subscribe. Those who do not subscribe represent the group of households whose valuations of the additional channels ranges between zero and the subscription fee. Modifying the N-P-M model to account for this, we estimated that in 1992 households choosing not to subscribe to cable would only be willing to pay an average of $5.98 annually for a twelfth independent over-the-air channel.

As the subscription fee falls or the relative quality of cable service increases, a larger percentage of households choose to subscribe, and the average valuation for the remaining households falls. Thus, in table 3, as the cable subscription rate rises from 57% of homes passed in 1992 to 73% in 2000, the annual value per household falls from $5.98 to $3.54 for the remaining households choosing not to subscribe.

Multiplying the annual average value per non-subscribing passed household by the number of such households provides the total annual value of a channel for this group: $11.18 million in 1992, falling to $4.68 million in 2000. The present discounted value of these annual values is$46.67 million.

c. Summing up: producer plus consumer surplus. Adding before-tax station profits to the value to households not subscribing to cable provides the estimated social value of an independent TV station: $26.55 million in 1992,falling to $21.30 million in 2000 (see table 3). The present discounted social value for the years 1992 to 2000 is $139.2 million.

C. QUALIFICATIONS AND SECOND ORDER EFFECTS

Estimating the social value of UHF TV station is, of course, somewhat more complex than the foregoing analysis would suggest. A more refined analysis would take into account other changes resulting from taking a channel off the air. The following issues might be addressed in such an analysis:

1. Reducing the Number of Over-the-air Channels May Increase Cable Penetration.

a. Cable operators may increase the number of homes passed. In our analysis we assumed that taking stations off the air will have no effect on the number of homes passed by cable. Because cable operators are more likely to serve an area with fewer stations available over the air, this assumption would lead us to overstate the loss associated with converting UHF TV channels to mobile services. The magnitude of the estimation error is likely to be trivial if one is considering removing one or two stations in Los Angeles.

This might not be true, however, if a large percentage of UHF TV channels were converted to mobile services. In that case, a significant number of people would be better off because they would now be able to enjoy the benefits of cable. In addition, there would be an increase in producer surplus (profits) accruing to cable operators (and other suppliers up the vertical chain).

b. More households may choose to subscribe to cable. Some households that are passed by cable but do not now subscribe would subscribe if the number of over-the-air channels were reduced. For those viewers, the reduction in welfare would be less than if they did not have the option of subscribing.But our analysis treats them as if they continued not to subscribe. Our analysis also does not account for the increase in profits of cable operators and other suppliers. The cost of supplying cable service to homes already passed is likely quite low relative to the subscription fee, so the gain in producer surplus per additional subscriber may be large.

2. Reducing the Number of Over-the-Air Channels May Harm Cable Subscribers.

To simplify our analysis we assumed that households who subscribe to cable incur no loss of welfare when the number of TV channels available over the air is reduced. This assumption may understate the welfare loss for two reasons:

a. Programming may be lost. If the programming that is no longer broadcast was initially carried by cable and continues to be carried, there will be no loss to cable subscribers. Dropping the TV broadcast would just eliminate duplication. This could happen if the TV station continued to provide cable systems with programming, including local advertising, even though the station no longer broadcast over the air. If this also resulted in positive profits for the station our analysis would overstate the loss in producer surplus and the total welfare loss. Another possibility is that the cable system would substitute a station with programming virtually identical to that of the station going off the air.

However, if the programming that is no longer broadcast does not continue on cable, there could be a small loss to cable viewers. These viewers would still have the same number of unduplicated video channels as before, but the programming on (at least) one of the channels would be different. This alternative programming would likely be less valuable to viewers than the original programming, or else the cable system would have offered it initially. Of course, this is not necessarily true, since broadcasters and cable operators may not have the incentive to supply programming that is most valued by viewers.[54]

If the programming that is dropped was never carried by cable, the loss might be greater than in the above cases. In this case cable subscribers would have fewer unduplicated video channels available. But, since the total number of channels available to cable subscribers is so great, the harm from losing a channel would likely be small. Moreover, since the programming was not initially picked up by the cable system, it would probably not have been of great value to most cable viewers. If it were,the cable system might still be able to offer it even though it is not available over the air.

Taking a station off the air could also affect cable subscribers outside the local viewing area, if their cable system picked up the station as a distant signal. In such a case, the above analysis would apply to those subscribers as well.

b. Cable prices may increase. The second way cable subscribers could be harmed when a station discontinued broadcasting is through the reduction in competition between over-the-air broadcasters and cable operators. The loss to those households that continued to subscribe even at the higher price would just be offset by the gain to cable operators, with no change in consumer plus producer surplus. But social welfare would be reduced if subscribers were to drop service as a result of the price increase. The maximum loss to such a household would be the amount of the price increase,since it would have the option of continuing service at the higher price.The loss to the cable operator from a customer dropping off the system would be the revenue it received from the customer at the old prices minus the cost of providing service to that customer.

3. Taking a Channel Off the Air May Increase Profits of Other Broadcasters.

We assumed that the change in producer surplus from reallocating a UHF TV channel can be estimated by the change in profits of the lowest valued station with the same coverage area. In theory, however, one should estimate the change in profits of all stations in the market. If a station were to shut down, many viewers and much advertising revenue would shift to other stations, and the reduction in total market profits would be less than the change in the profits of the least profitable station. Thus, our assumption overstates the loss of producer surplus.

54 Regulation of copyrights is another complication not considered in our earlier discussion of broadcasters' choice of programming. Compulsory licensing of distant signals shown on cable systems may distort cable operators' choices among programming. A cable operator may prefer material that is subject to a compulsory license because it is inexpensive. But social welfare might be greater if the cable system offered other programming that is not subject to a compulsory license.

4. The Private Cost Saving to a Broadcaster From Discontinuing Service May Exceed the Social Cost Saving

We assumed that the private costs saved by broadcasters when a station is shut down are equivalent to the social costs. But this may not be the case if there is a large gap between the amount broadcasters pay for programming and the marginal cost of making that programming available.Such a gap may exist because of the large fixed cost to produce programming.If program suppliers were to charge only the marginal cost of distributing programming, they could not recover the fixed costs of creating that programming. Taking this into account would tend to increase the estimate of the social cost of taking a television station off the air.

5. The N-P-M Estimates May No Longer Be Valid Because of Changes in the Video Market

Our estimates of the percentage of income a household would be willing to pay for an over-the-air channel are based on a model estimated by Noll,Peck, and McGowan with 1969 data. Much has changed since then. One of the most significant developments is the mass marketing of video cassette recorders (VCRs), which were just being developed for the home market in 1972. Now over 68% of television households have them.[55] The effect of VCRs on the value of an over-the-air channel is ambiguous, however, because VCRs are both substitutes for and complementary to broadcast programming. On the one hand, VCRs provide an alternative source of programming, reducing the value of an additional television station. On the other hand, VCRs permit time shifting of broadcast material, increasing the value of an over-the-air channel.

Another difficulty is that the N-P-M model may not provide reliable predictions for markets which have a much greater number of over-the-air channels than the average number of channels in the sample of cable systems used to estimate the model.[56] N-P-M do not report that average, but we inferred from their discussion that most cable systems at the time the sample was taken had 12 channels or fewer.[57] This is fewer than the 16 channels available over-the-air in Los Angeles. Whether the difference is sufficient to create a significant forecasting error is unclear.

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[55] Television Bureau of Advertising, "Trends in VCR Usage," (New York: April, 1990), p. 3.

[56] In general, one has the greatest confidence in forecasts made at the average value of the data used to estimate a model. That confidence declines the further away one goes from this average. See Peter Kennedy, A Guide to Econometrics, 2d ed. (Cambridge, Mass.: The MIT Press, 1985), p. 204.

[57] Noll, Peck, McGowan, p. 186.

V. VALUE OF SPECTRUM USED IN CELLULAR TELEPHONE SERVICE

A. BACKGROUND AND ASSUMPTIONS

This section provides some background and assumptions about the cellular market and cellular technology.

1. The Cellular Market in Los Angeles

In 1988, approximately 13 million people lived within the franchise area of the two existing cellular carriers in Los Angeles.[58] Starting with this figure, we projected the annual population in the Los Angeles cellular market through the year 2000 by assuming an annual growth rate of 1.5%.[59]

Market penetration is far more difficult to project. In 1988, Pacific Telesis Cellular (PacTel), the Los Angeles wireline cellular carrier, had about 170,000 subscribers in Los Angeles.[60] This represents a per-system penetration rate of 1.3%, or a total penetration rate of 2.6%, assuming that the Los Angeles non-wireline carrier had a similar number of subscribers as the PacTel system. According to securities analyst Dennis Liebowitz, the cellular industry consensus forecast of total penetration is 12-15% for the year 2000.[61] For our model, we assumed that total penetration in Los Angeles will grow by one percentage point a year to 12.6% in 1998, will reach 13% in 1999, and will remain there in 2000.

To project cellular revenues we started with an industry estimate that the average monthly bill in Los Angeles at the end of 1988 was $140.[62] This was considerably more than the

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[58] Dennis Liebowitz, Eric Buck, and Joel Gross, The Cellular Communications Industry (New York: Donaldson, Lufkin, and Jenrette, May, 1989) p. 53. They report a population of 12,855,642 for the Los Angeles Metropolitan Statistical Area (MSA) in 1988.

[59] This is the same growth rate we assumed in projecting the number of television households in Los Angeles.

[60] Hatfield and Ax, 1988, p. 20.

[61] Dennis Liebowitz, Eric Buck, and Joel Gross, The Cellular Communications Industry (New York: Donald, Lufkin, and Jenrette, Fall, 1989), p. 11. If this turns out to be excessively optimistic, the value of spectrum in cellular could be considerably less than our estimates.

[62] Phase I Comments on Regulation of Cellular Radiotelephone Utilities, California Public Utilities Commission, Division of Ratepayer Advocates, (San Francisco, California, March 1989), p. 1.3.6. This is consistent with estimates by California cellular carriers that average monthly usage is 230 minutes (80% peak and 20% off-peak). Applying this usage to the December 1988 Los Angeles time charges of $.45 per peak minute, and $.27 per off-peak minute, and adding the $45 monthly fee results in a monthly bill of $140.22. Ibid.

national average monthly bill of $95.[63] We assumed that average monthly revenue per subscriber falls by $5 each year from the 1988 Los Angeles average to reach $80 per month in 2000. This follows Liebowitz, Gross, and Buck, who make a similar assumption in their cellular model for a "composite city/company with 15 million population."[64] Such a decline could be both the result of reductions in the charge for a given amount of service and the addition of customers with lower than average calling volumes as total penetration increases.

For simplicity, we assumed that average usage per subscriber remains approximately the same over time. This would be consistent with a simultaneous reduction in usage charges for high-volume users, and lowered monthly subscription fees for low-volume users. On the one hand, lower usage charges for high volume users would tend to increase usage for existing subscribers. On the other hand, offering new packages with reduced monthly subscription fees and higher usage charges would tend to attract new subscribers with usage lower than the average for existing subscribers. We assumed these two effects approximately balance out. This assumption simplified the estimation of the cost of serving a given number of subscribers.

2. Cellular Technology

The fundamental concept underlying cellular technology is that the reuse of the same frequencies in geographically separated areas permits a small amount of spectrum to accommodate a large number of users. The term "cell" refers to the area served by a base station radio transmitter/receiver. With the use of low powered transmitters, relatively little geographic separation is needed between cells using the same frequency. The radio equipment in each cell is connected to a mobile telephone switching office (MTSO) by either microwave radios or landlines. The MTSO is in turn connected to the public switched telephone network. As a vehicle passes through cells the MTSO automatically switches the mobile radio to a frequency in the cell with the strongest signal.

There are three basic ways to increase the capacity of a cellular system. The first is cell division. By reducing transmitter power, and hence cell size, the same frequency can be reused at closer distances. Doubling the number of cells doubles the number of users that can be served until very small cell sizes are reached (about two miles in diameter). The major cost of this approach is the expense of additional cell sites, i.e., the fixed cost of the antennas, of the

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63 Ibid.

64 Liebowitz, Gross, and Buck (Fall 1989, pp. 13-14.) They assumed that monthly revenue per subscriber is $105 in 1988 and gradually falls to $70 in 2000.

facilities used to house the base station radios and mount the antennas associated with each cell, and of the links between that equipment and the MTSO.

The second method is to increase the number of radio frequency (rf) channels per cell by acquiring additional spectrum. Doubling the amount of spectrum will also approximately double the system capacity.[65] In 1986 the FCC added an additional 10 megahertz of spectrum to the original 40 megahertz cellular allocation. This gave each of the two cellular systems per market a total of 25 megahertz of spectrum.

Finally, one can increase capacity by increasing the number of voice channels per rf channel. With current analog cellular systems each voice channel requires one rf channel. But with digital systems it is possible to provide six or more voice channels per rf channel. One way to do this is with "time-division multiplexing." By rapidly taking turns, several conversations can be carried simultaneously on a single rf channel. At any one instant, only one conversation is being carried on the channel, but because the time slots are so short, the users are unaware that they are sharing a channel. The U.S. cellular industry has recently adopted a time division multiple access (TDMA) digital standard, and some operators plan to deploy systems based on it sometime in 1992. At first, these systems are expected to provide three voice channels per rf channel, and in 1994 each rf channel is expected to handle six voice channels.[66] Recently, PacTel Corporation has proposed to use a different digital multiplexing method known as code division multiple access (CDMA). By assigning each transmission a unique code sequence, CDMA permits multiple simultaneous conversations to share the same spectrum without interfering with each other, and has the potential to increase capacity ten to twenty fold.

3. Trunking Efficiency

Increasing the number of voice channels per cell, either by adding spectrum or multiplexing, also increases system capacity through trunking. Because subscribers rarely all wish to make a call at exactly the same moment, it is not necessary to dedicate a voice channel for the exclusive use of each subscriber. For a given probability of getting a dial tone, the channels needed per subscriber declines as subscribers in a group with access to a common set of voice channels (or "trunk group") increases. The same phenomenon is observed in the demand for bathrooms in a household. Doubling the number of members of a household does not double the number of bathrooms needed to assure a given probability of finding one vacant.

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[65] Increasing the number of channels per cell increases trunking efficiency, so doubling the amount of spectrum will more than double capacity. This is discussed below.

[66] Conversation with James Proffitt of PacTel, July 19, 1989.

Figure 7 and the adjoining table show the number of users per channel that can be accommodated as a function of the number of channels in the trunk group, assuming a 2% blocking probability and an average peak hour traffic per user of 0.0258 erlangs.[67] The number of users per channel increases rapidly as the number of channels is increased from 1 to 20. Twenty channels can accommodate almost 26 users per channel. With 40 channels 30 users can be accommodated per channel. Beyond 40 channels, the number of users per channel continues to increase but at a much diminished rate, reaching 33.3 users per channel with an 80 channel trunk group.

Throughout our analysis we calculated trunking based on the total number of voice channels per cell sector. This is fully appropriate for an all-analog or an all-digital system. But it may not be appropriate for the mixed analog/digital systems which will prevail as existing systems convert from analog to digital. These systems will have some analog and some digital voice channels, but only dual mode mobile units will be able to trunk across both analog and digital channels. If all mobile units were dual mode, the fact that some channels are analog and others digital would not matter in calculating trunking efficiency. But not all subscribers will trade their analog mobile units for new dual mode ones. Thus our calculations that assume all mobile units can trunk over all channels overestimate trunking efficiency for mixed systems. The effect of this simplification on our estimates of the value of additional spectrum is not clear, however, because the overestimate applies both to cellular systems with and without additional spectrum, and the size of the overestimate appears to depend on the proportion of dual mode and analog mobile units in a system, which in turn depends on the amount of spectrum assigned to the system.

B. ACCOMMODATING DEMAND THROUGH 1991 WITH ANALOG TECHNOLOGY

Our analysis assumes use of analog technology through 1991 and the industry TDMA digital standard thereafter. Both technologies require 60 kilohertz (.06 megahertz) per two-way rf channel. Thus, a cellular system with 25 megahertz of spectrum has about 416 rf channels available, without frequency reuse. Subtracting for channels used for system control functions such as assigning mobile units to cells, a total of 395 rf channels are available for voice traffic.[68] These channels may be spread over four, seven, or twelve cells. Based on a conversation with a PacTel engineer, we assumed that cellular systems in Los Angeles will

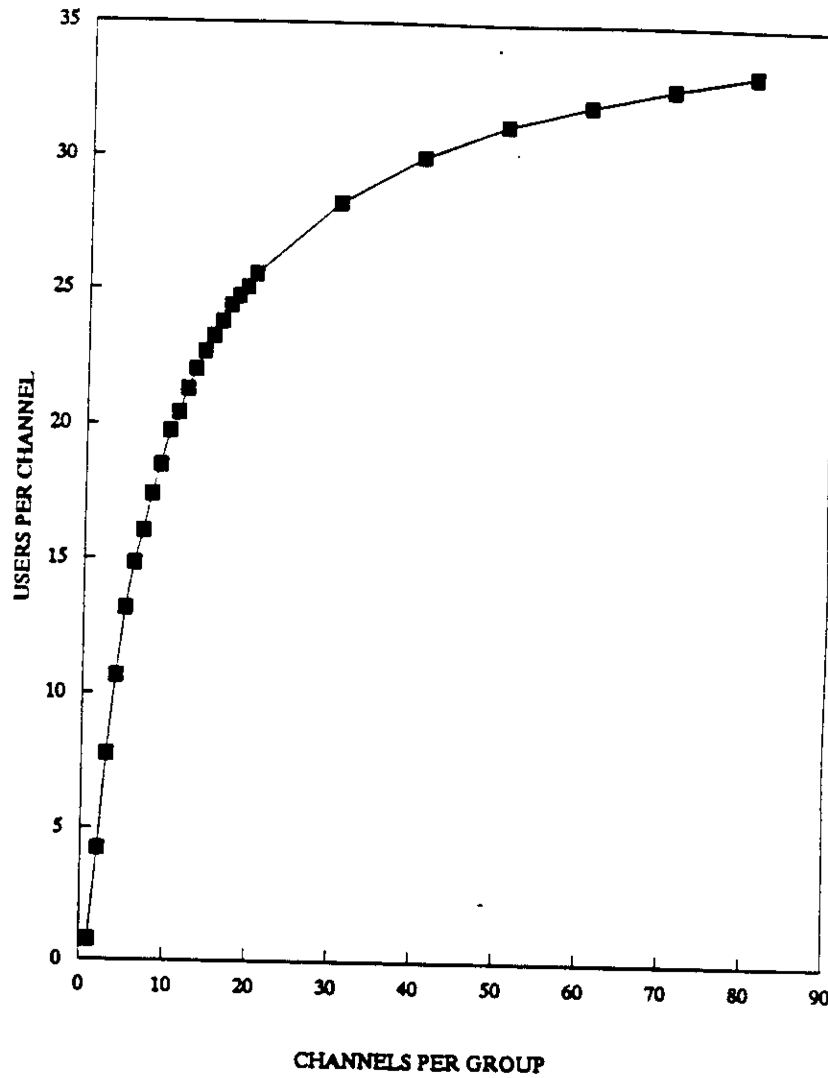
[67] Each 60 minutes of conversation during the peak hour represents one erlang. Thus, we assumed that an average subscriber uses his phone 0.0258 x 60 = 1.548 minutes during the peak hour.

[68] Hatfield and Ax, p. 19.

FIGURE 7

TRUNKING EFFICIENCY

CHANNELS PER GROUP	USERS PER CHANNEL
1	0.8
2	4.3
3	7.8
4	10.7
5	13.2
6	14.9
7	16.1
8	17.4
9	18.5
10	19.8
11	20.4
12	21.3
13	22.1
14	22.7
15	23.3
16	23.8
17	24.4
18	24.8
19	25.1
20	25.8
30	28.3
40	30.0
50	31.2
60	32.0
70	32.7
80	33.3



NOTES:

1. ERLANG B, TABLE 4, P. 39–12, ITT REFERENCE DATA FOR RADIO ENGINEERS
2. 2 % OF CALLS BLOCKED DURING PEAK HOUR
3. PEAK HOUR TRAFFIC PER USER = .0258 ERLANG

continue to use a seven cell, three sectors per cell pattern.[69] This cell pattern may then be repeated over and over as additional capacity is needed.

This information can be used to estimate the number of cell sites needed to serve a given number of subscribers. On average, with a seven cell pattern and analog technology, each cell can accommodate a maximum of 56.4 voice channels. The number of subscribers that can be accommodated per voice channel depends on the number of channels in the trunk group. In this case, the trunk group is a cell sector. With three sectors per cell there are an average of 18.8 voice channels per trunk group. From figure 7, this implies that each voice channel can serve about 25 subscribers. Thus each cell can serve about 1,410 subscribers. For 1991, the last year for which we assume exclusive use of analog technology, we assumed approximately 381,000 subscribers for each of the existing cellular operators in Los Angeles. Serving these subscribers would require about 270 cells per system, given our assumptions.

C. A BRIEF COMPARISON OF ANALOG AND DIGITAL SYSTEMS

Digital cellular systems are expected to be less costly per subscriber than the current analog systems. To illustrate this we calculated the investment cost per subscriber for a fully loaded cell in a system with 25 megahertz of spectrum. This is shown in table 4. It should be noted that the welfare analysis developed later in the paper is not based on the numbers presented in this table, but on a more complex dynamic cost model which does not assume that all cell sites are fully loaded. Of course, assuming cell sites are not fully loaded increases the estimated cost per subscriber. Moreover, our model includes the cost of switch investment, while the estimates shown in table 4 do not.

Table 4 provides rough estimates of the cost per subscriber for an analog system, a digital system with three voice channels per rf channel (available in 1992), and a digital system with six voice channels per rf channel (available in 1994). We assumed that the fixed cost of a cell site is $600,000 and that the variable cost per fully equipped analog channel is$10,000.[70] We also assumed that the variable cost per digital rf channel with 3 time slots would be $15,000 and with 6 time slots $20,000.[71] The cost of a base station radio comprises most of the variable

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[69] Conversation with Jim Proffitt, July 19, 1989.

[70] Hatfield and Ax (p.23) estimated the fixed cost per cell site as $483,000. This was based on 1982 data for the initial 24 site Los Angeles system. We increased their estimate to $600,000 to reflect the increase in land prices. They estimated variable cost per channel as $9,300. Since the cost of electronic equipment has risen much less than land costs, and in many cases fallen even in nominal terms, we made a smaller adjustment to this figure.

[71] Conversation with Jim Proffitt of PacTel, August, 25, 1989.

Table 4

INVESTMENT COST PER CELLULAR SUBSCRIBER: COMPARISON OF CURRENT ANALOG SYSTEMS WITH TDMA DIGITAL SYSTEMS

	TECHNOLOGY		
	Analog	Digital 1992	Digital 1994
Voice channels per cell	56.4	169.2	338.4
Total cost per loaded cell ($)	1,164,000	1,446,000	1,728,000
Constant trunking efficiency case			
Subscribers per voice channel	25.0	25.0	25.0
Subscribers per cell	1,410.0	4,230.0	8,460.0
Cost per subscriber ($)	826	342	204
Variable trunking efficiency case			
Subscribers per voice channel	25.0	31.2	33.3
Subscribers per cell	1,410.0	5,279.0	11,268.7
Cost per subscriber ($)	826	274	153
% cost reduction from trunking		19.9%	24.9%

ASSUMPTIONS:

(1) Cells are fully loaded.
(2) Cost per base station radio ($)
Analog -- 1 voice chan. per rf channnel 10,000
Digital 1992 -- 3 voice chan. per rf chan. 15,000
Digital 1994 -- 6 voice chan. per rf chan. 20,000
(3) Fixed cost per cell site ($) 600,000
(4) Fixed cost of switch is not included in analysis.

cost per channel.[72] For convenience, we will refer to all variable investment per channel as a base station radio.

Table 4 was calculated under two scenarios. First, we made the calculations assuming 25 subscribers per voice channel for all three cases. Then we accounted for the increased trunking efficiency associated with an increased number of voice channels per cell sector. Assuming constant trunking efficiency we estimated that the investment cost per subscriber in a fully loaded cell is about $826 for an analog system, $342 for the digital system to be introduced in 1992, and $204 for the 1994 digital system. Taking into account increased trunking efficiency reduces the digital cost estimates 20 percent for 1992 and 25 percent for 1994, to $274 and $153 respectively.

Of course, the cost per subscriber would be greater for systems with less than 25 megahertz of spectrum. For example, using the same methodology, a pure digital system in 1992 with 18 megahertz would have a system investment cost (excluding switching) per subscriber of $333 instead of the $274 shown in table 4 for the variable trunking efficiency case.[73]

In assessing the cost advantage of digital systems one must also take into account the cost of the mobile units. At least initially, digital mobile units will cost more than analog ones. If the manufactured cost of an analog mobile unit is about $300 and digital radios are between 30 and 80 percent more expensive, this would add between $90 and $240 to the per subscriber investment cost, which is far less than the savings in system investment costs.[74]

Even if digital systems did not have a cost advantage, cellular operators might introduce them because they offer a number of service advantages: they provide greater privacy, minimize distortion, are likely to be superior for linking digital devices such as computers (since the data does not need to be converted from digital to analog and back to digital), and may facilitate the offering of various enhanced services.

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[72] The variable cost per channel also includes the variable cost of investment in microwave links to the mobile telephone switching office (MTSO) and possibly some limited variable cost at the MTSO. The cost of leased lines for backhaul are included in our model as operating expenses.

[73] A system with 18 MHz would have about 40 rf channels usable for voice. We assumed that in 1992 three voice channels can be derived from each rf channel. This implies a total of 120 voice channels per cell. Assuming three sectors per cell implies 40 voice channels per sector and 30 subscribers per voice channel (from figure 7).

[74] The $300 estimate is from a conversation with Doug Collette of Advanced Mobile Communications, May 15, 1990. The 30% cost premium estimate for digital radios is from a conversation with Jim Proffitt, July 19, 1989. However, an article in Mobile Phone News stated that the prices of digital mobile phones could be 50-80% higher than those of analog units. October 11, 1990, p. 5.

D. THE TRANSITION TO DIGITAL CELLULAR SYSTEMS WITHOUT ADDITIONAL SPECTRUM: THE BASE CASE

The benefits of additional spectrum are the gain in producer and consumer surplus compared to what they would have been under the status quo. Thus, to calculate these benefits one must first model cellular costs for the case where no additional spectrum is available. We will refer to this as the "base case."

Beginning in 1992, when digital cellular systems become available, existing operators will no longer have an incentive to cell divide -- indeed, they will find themselves with more cells than they would choose if they were starting over. Instead of the 270 cell sites we forecast for 1991, an all digital cellular system would only need about 90 cell sites if it provided three voice channels per rf channel, and about 45 cell sites if it provided six voice channels. If increased trunking efficiency is taken into account, the number of cell sites needed is reduced to 72 assuming three voice channels per rf channel, and 34 assuming six channels.[75] We assumed that investments in cell sites are sunk costs, i.e., operators could not reduce costs by eliminating existing cell sites. We treated investments in analog base station radios as sunk costs as well.

With the introduction of digital technology, the least costly way for an existing cellular operator to expand capacity (without using additional spectrum) would be to convert analog channels to digital channels at the existing cell sites.[76] Replacing an analog rf channel with a digital one initially will triple the number of voice channels available (for a net gain of two voice channels).

On a fully loaded system, for each analog base station radio replaced with a digital base station, approximately twenty-five analog mobile units must be replaced as well.[77] This is because analog radios cannot operate on digital channels, and service quality would suffer if analog users were simply loaded onto fewer analog channels. In our analysis we assumed that it costs $650 to replace an analog mobile unit with a dual mode digital radio.[78] This estimate

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[75] The number of cells needed was calculated by dividing our prediction of 381,000 subscribers in 1991 by the estimated number of subscribers per cell shown in table 5.

[76] In our model the only reason equipment is replaced is to expand output. A more refined analysis would account for all sources of obsolescence.

[77] Fewer analog mobile units would have to be replaced initially if high-use subscribers would convert first, as is likely. This would reduce the cost of conversion.

[78] The cost of manufacturing an analog car cellular mobile unit is about $300. Telephone conversation with Doug Collette of Advanced Mobile Communications, May 15, 1990. Jim Proffitt of PacTel estimated that digital mobile telephones would cost about 30% more than analog. Telephone conversation July 19, 1989. However, an article in

of the cost of producing, distributing, and installing a dual mode digital mobile radio may, however, overstate the cost associated with prematurely replacing analog mobile radios. A better estimate might be the least amount needed to induce the required number of analog users to convert to digital mobile units. We do not know what this is, but it can be no more than the installed cost of new digital units, and it might be less for two reasons. First, digital units may have service advantages for which subscribers would be willing to pay. Second, the used analog units may have some resale value.

An interesting question related to the transition from analog to digital technology is how operators will induce subscribers to replace analog mobile units with digital ones, and what the economic efficiency consequences of the different approaches are. One possibility is to charge digital users less for airtime. The price differential would reflect the fact that digital mobile units use less scarce spectrum. A price differential for usage would seem to be part of a welfare maximizing price structure, since the marginal cost of providing airtime to analog users exceeds that for digital users. With such a price differential high volume users would have the greatest incentive to switch to digital. Some of the used analog mobile phones replaced by high volume users might be sold to very low volume new subscribers who would be happy to accept a higher usage charge in exchange for a much reduced capital investment in the mobile unit.

The question of how analog users are induced to convert to digital raises the issue of who pays the cost of such conversion. We assumed that cellular operators pay for the replacement of analog mobile units needed to create extra capacity. This would be the case if cellular systems owned all the mobile units and leased them to users. But given that most mobile units are owned by subscribers, owners of analog mobile units may bear some of the cost. We did not refine our analysis of this issue since our primary concern is with the sum of consumer and producer surplus and not the distribution of benefits and costs between consumers and producers.

A second phase of conversion to digital is expected to occur in 1994 when cellular operators upgrade from three voice channels per rf channel to six. If all goes as planned, the digital mobile units bought before 1994, which will initially operate on rf channels with three time slots, will also operate on six time slot channels without modification. It is also expected that only a software change will be needed in the base station digital radios to upgrade from three

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Mobile Phone News stated that the prices of digital mobile phones could be 50-80% higher than those of analog units. October 11, 1990, p. 5. Assuming a 50% cost premium would imply a manufactured cost of about $450 per mobile telephone. We assumed that the distribution and installation costs, including the cost of the customer's time, for replacing an analog unit with a digital one would be about $200.

time slots to six. This upgrade plus any additional investment in backhaul facilities are estimated to cost about $5,000 per base station radio.[79]

At this price it would be far cheaper to upgrade a digital base station radio than to replace an analog base station radio with a six time slot digital radio. Upgrading a digital base station radio produces a net gain of three voice channels for $5,000, or $1,667 per channel. Converting an analog base station radio to a six time slot digital radio would yield a net gain of five voice channels, but would cost about $20,000 for the new digital base station radio, plus the cost of replacing the analog mobile units that operated on the converted analog channel. This implies a cost of $4,000 per new voice channel just to pay for the base station radio. And, if 25 analog mobile units need to be replaced with dual mode digital mobiles at $650 per unit, the total cost per new voice channel would be $7,250.

1. Calculating Investment Inputs and Costs for the Base Case

The calculation of costs and profits for an existing cellular operator with 25 megahertz of spectrum is shown in table 5. The first step in making this calculation for the base case is to determine the inputs needed to meet the projected demand. Looking at the row labeled "cell sites" one can see that in 1991, the last full year of an all-analog system, an operator in Los Angeles would need 270 cell sites to meet the predicted demand. Given our assumption that investments in cell sites are sunk costs, the operator would maintain this number of sites throughout the period studied.[80]

The total number of voice channels was calculated by dividing the projected number of subscribers at the year end by the number of subscribers per voice channel.[81] Note that we accounted for the fact that investment must be made ahead of demand by estimating annual investment costs based on the number of subscribers at the end of each year, but calculated revenues based on the average of the number of subscribers during each year. In other words, we assume that an operator must make sufficient investment at the beginning of each year to satisfy the projected demand at the end of the year.

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[79] Conversation with James Proffitt, PacTel official, August 25, 1989.

[80] The assumption that one can not reverse past investments is an important difference between our analysis and that of Hatfield and Ax. Their analysis of the cost savings from additional spectrum makes no distinction between a system starting from scratch and one that has already invested in cell sites.

[81] Apparent slight discrepancies in such arithmetical operations can be accounted for by rounding. All figures in the table are carried out to more places internally by the spreadsheet program and all calculations are carried out using these additional places.

Table 5

REVENUES, COST, AND PROFITS OF SERVING CELLULAR SUBSCRBIBERS IN LOS ANGELES 1992-2000
BASE CASE: AN INCUMBENT OPERATOR WITH 25 MHZ

	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
POPULATION (000s)	13,594	13,798	14,005	14,215	14,428	14,644	14,864	15,087	15,313	15,543
TOTAL CELLULAR MARKET										
Penetration rate	5.6%	6.6%	7.6%	8.6%	9.6%	10.6%	11.6%	12.6%	13.0%	13.0%
Subscribers year end (000s)	761	911	1,064	1,222	1,385	1,552	1,724	1,901	1,991	2,021
% growth		19.6%	16.9%	14.9%	13.3%	12.1%	11.1%	10.2%	4.7%	1.5%
INCUMBENT CELLULAR SYSTEM										
Subscribers										
Share of total additions		50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Share of total market	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Subscribers year end (000s)	381	455	532	611	693	776	862	950	995	1,010
Subscribers added (000s)		75	77	79	81	84	86	88	45	15
Average # subscribers (000s)		418	494	572	652	734	819	906	973	1,003
% growth in subscribers			16.9%	14.9%	13.3%	12.1%	11.1%	10.2%	4.7%	1.5%
Revenues										
Per subscriber/month ($)	125	120	115	110	105	100	95	90	85	80
Total annual revenues ($ m)		601.9	681.4	754.7	821.4	881.2	933.8	978.8	992.4	962.7
Pres. value total rev. ($ m)	4,686.1									
Cell sites										
Total	270	270	270	270	270	270	270	270	270	270
New		0	0	0	0	0	0	0	0	0
Channels										
Subscribers per voice channel	25	24.8	25.8	25.8	25.8	28.3	28.3	28.3	30	30
Total voice channels	15,225	18,360	20,627	23,691	26,843	27,426	30,463	33,586	33,586	33,677
Voice channels per sector	18.8	22.7	25.5	29.3	33.2	33.9	37.6	41.5	41.5	41.6
New voice channels		3,135	2,267	3,064	3,151	583	3,038	3,123	0	91
Total analog rf channels	15,225	13,658	12,524	12,524	12,524	12,524	12,177	11,553	11,553	11,535

New analog rf channels		-1,567	-1,134	0	0	0	-347	-625	0	-18
Total 3X digital rf channels		1,567	2,701	1,680	629	435	0	0	0	0
New 3X digital rf channels		1,567	1,134	-1,021	-1,050	-194	-435	0	0	0
Total 6X digital rf channels		0	0	1,021	2,072	2,266	3,048	3,672	3,672	3,690
New 6X digital rf channels		0	0	1,021	1,050	194	781	625	0	18
Total rf channels in use	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225
Unused rf chan. prev. period		0	0	0	0	0	0	0	0	0
Mobile radios										
Replacement mobile radios		38,872	29,247	0	0	0	9,811	17,673	0	544
Investment cost										
Cell sites ($ m)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RF channels ($ m)		23.5	17.0	5.1	5.3	1.0	9.1	12.5	0.0	0.4
Replacement mobile radios ($m)		25.3	19.0	0.0	0.0	0.0	6.4	11.5	0.0	0.4
Switch (MTSO) ($ m)		1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total ($ m)		49.8	36.0	5.1	5.3	1.0	15.5	24.0	0.0	0.7
Invest./ new subscriber ($)		666.4	468.6	64.6	64.6	11.6	180.1	271.3	0.0	47.9
Invest./ new sub./ mth. ($)		8.8	6.2	0.9	0.9	0.2	2.4	3.6	0.0	0.6
Pres. value total invest. ($m)	104.4									
PV invest./PV revenue	2.2%									
PV invest./PV total cost	4.4%									
Operating expenses										
Op. expenses per avg. sub. ($)		360	289	247	230	210	204	189	186	173
Total operating expenses ($ m)		150.5	142.7	141.2	149.9	154.2	167.1	171.3	181.0	173.5
% of revenue		25.0%	20.9%	18.7%	18.3%	17.5%	17.9%	17.5%	18.2%	18.0%
Admin. and gen. expenses										
G & A per avg. sub. ($)		600	567	386	293	238	204	174	157	140
Total G & A ($ m)		250.8	280.0	220.7	191.0	174.8	167.1	157.7	152.7	140.4
% of revenue		41.7%	41.1%	29.2%	23.3%	19.8%	17.9%	16.1%	15.4%	14.6%
Marketing expenses										
Marketing per new sub. ($)		600	550	500	450	400	400	400	400	400
Total marketing ($ m)		44.8	42.3	39.5	36.6	33.4	34.4	35.3	18.0	6.0
% of revenue		7.4%	6.2%	5.2%	4.5%	3.8%	3.7%	3.6%	1.8%	0.6%

Total cost										
Investment + all expenses ($m)		495.9	500.9	406.5	382.8	363.4	384.1	388.3	351.7	320.6
Total cost/total revenue		82.4%	73.5%	53.9%	46.6%	41.2%	41.1%	39.7%	35.4%	33.3%
Present value total cost ($ m)	2,373.4									
PV cost/PV revenue	50.6%									
Profit										
Pretax annual profit ($ m)		106.0	180.4	348.1	438.6	517.8	549.7	590.5	640.7	642.1
After tax annual profit ($ m)		67.9	115.5	222.8	280.7	331.4	351.8	377.9	410.1	411.0
PV pretax profit ($ m)	2,312.7									
PV after tax profit ($ m)	1,480.1									
Residual value in year 2001										
Ten times yr. 2000 profit ($ m)	4,109.7									
Present value residual value	1,584.5									
Market value in 1991 ($ m)										
PV profit + PV residual value	3,064.6									
Market value/population ($)	225									

ASSUMPTIONS:

Spectrum available (MHz)	25	Cost to upgrade base station from 3 to 6 voice channels	$5,000
Max. rf chan. without reuse	416.7	Cost per cell site	$600,000
RF channels available for voice	395.0	Cost per dual mode mobile radio	$650
Max. rf channels per cell	56.4	Discount rate	10%
Cost per base station radio		Tax rate	36%
3 voice chan. per rf chan.	$15,000		
6 voice chan. per rf chan.	$20,000		

The number of subscribers per voice channel used in calculating the number of voice channels needed to meet demand was derived from the trunking efficiency table (figure 7). As discussed above, trunking efficiency depends on the number of voice channels in a cell sector. Assuming three sectors per cell and 270 cells, there are a total of 810 sectors. Dividing the total number of voice channels by the total number of sectors gives the number of voice channels per sector shown in table 5. To avoid solving simultaneous equations, we used the voice channels per sector from the previous period in calculating trunking efficiency.[82] For example, for 1992 we used the number of subscribers per voice channel associated with the voice channels per sector in 1991.[83]

We assumed that in 1992 and 1993 capacity will be expanded by replacing analog base station radios with digital radios with three time slots, i.e., radios that can provide three times the capacity as current analog systems. To find the number of new base station radios needed we first calculated the number of new voice channels required in each year to serve the projected demand. This is simply the difference between the total number of voice channels projected for the year in question and the total number projected for the previous year. For 1992 this is 3,135. Since each analog base station radio replaced with a digital base station radio provides a net addition of two voice channels, approximately one half of this total -- 1,567 base station radios -- must be replaced in 1992. In addition, a total of about 38,872 analog mobile radios must be replaced, since in 1992 each analog base station radio replaced handled 24.8 subscribers. The same methodology is used to calculate the number of analog base station radios and mobile units replaced in 1993.

In 1994 existing systems will increase capacity by converting digital base stations with three time slots to ones with six. For example, in our model the 3,064 new voice channels needed are provided by converting about 1,021 base stations, since each conversion yields a net increase of three voice channels. This process of upgrading digital base stations continues through 1997.

In 1997 the remaining 435 digital base station radios with three time slots are upgraded, yielding 1,305 voice channels. But a total of 3,038 new voice channels are needed in that year.

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82 The one exception to this was for 1991 when we used the subscribers per channel that correspond to the number of channels per sector in the year itself. Using linear interpolation of the trunking table one can see that 25 subscribers per voice channel corresponds to 18.8 voice channels per sector.

83 The program we used to read the trunking efficiency table finds the largest entry in the channels per sector column that is less than or equal the actual number of channels per sector. So when the number of voice channels per sector is 18.8 the program finds the number of subscribers per voice channel that corresponds to 18 voice channels per sector, 24.8.

The difference is made up by replacing 347 analog channels with digital channels, since each substitution yields a net increase of five voice channels. The approximately 9,811 analog mobile radios that were operating on these 347 analog channels must be replaced as well. This process of creating capacity by replacing analog base stations with digital ones with six time slots continues through the year 2000.

Our spreadsheet model accounts for one additional investment. We assumed that a new digital switch is added in 1992 to handle the growth in capacity through 2000, and that such a switch will cost one million dollars.[84]

The investment cost of meeting the projected demand is shown in the section of table 5 labeled "investment cost." Since no new cell sites are added, cell site investment is zero. Installing and upgrading digital rf channels accounts for the largest share of the present discounted value of investment cost, $55.2 million of a total of $104.4 million. Almost as large a component is the cost of replacing analog mobile radios with digital ones, $48.3 million. Perhaps the most surprising finding is the small size of investment costs relative to both total revenue and total cost. We estimated that the present discounted value (PV) of investment cost for the base case comprises only 2.2% of the PV of projected revenues, and 4.4% of the PV of total cost.

2. Operating Expenses and Other Costs for the Base Case

We relied on a report by Liebowitz, Buck and Gross (L-B-G) for estimates of operating, administrative, general, and marketing expenses, which comprise the remaining 95.6% of the present value of total costs.[85] The Liebowitz, Buck and Gross financial model assumes declining average operating, administrative and general expenses per subscriber over time. This may reflect both a time factor (learning by doing) and economies of scale (fixed administrative and other expenses).[86]

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[84] Lap Lee, a securities analyst, estimated that mobile telephone switching office costs $600,0000 - $700,000. The Cellular Communications Service Industry: A Qualitative Approach to Valuing and Differentiating Cellular Market, (New York: Salomon Brothers Inc., July 1988), p. 5.

[85] Cellular Communications Industry, Donaldson, Lufkin and Jenrette, May 1989, p. 17. We used their model of a cellular firm starting in 1988, the "late start-up" case. This has somewhat higher cost estimates than their financial model of a firm starting in 1985. Using the higher cost case produced more conservative estimates of cellular profits.

[86] We used the L-B-G cost estimates for 1988 to 1996 and applied them to our model for the years 1992 to 2000, both for incumbent operators and for a third cellular system. Assuming the same non-investment cost per subscriber for all firms may be an oversimplification, since this ignores possible differences in expenses between established and new firms. It may be more realistic to assume higher costs per subscriber for new systems. Making that assumption would imply a cost penalty for assigning spectrum to a third system, beyond the added investment costs accounted for in our

Based on this model, operating expenses per average subscriber were assumed to be $360 and 25% of revenue in 1992, and then to decline gradually, reaching $173 and 18% of revenue in 2000.[87] Administrative and general expenses were assumed to be $600 per average subscriber and 41.7% of revenue in 1992, and to fall to $140 and 14.6% of revenue in 2000. Marketing expenses were estimated as $600 per new subscriber in 1992, declining to $400 in 2000.[88]

3. Summary of Base Case

The calculations for the base case, as well as the other cases, are summarized in table 6. For the base case, both firms are assumed to have 25 megahertz of spectrum with subscribers divided equally between them. The present value of total cost and total revenue for each firm for the years 1992-2000 was estimated to be about $2.37 billion and $4.69 billion respectively. Thus, the present value of total cost comprised only about 50% of the present value of total revenue. For these years, the present value of before-tax and after-tax profit for each firm was about $2.31 billion and $1.48 billion respectively.

Since the market value of a firm is based on earnings over the expected life of the enterprise, and not just the years 1992-2000, we also calculated a residual value of the base case firm in the year 2001. We estimated this to be ten times the year 2000 after-tax profits, or $4.1 billion, as is shown in table 5.[89] The present value in 1991 of that residual value is $1.58 billion. Adding that to the present value of the after-tax profits for the years 1992-2000 provides a 1991 market value of $3.06 billion for a base case cellular firm. Dividing this by the estimated

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estimates. One way to model lower per-subscriber expenses for incumbents than new entrants would be to estimate these expenses for incumbents using the L-B-G figures for 1992 to 2000 and estimate them for new entrants using the figures for 1988 to 1996.

[87] A major component of operating expenses is charges paid to local exchange carriers for interconnection to the public switched network and for private lines connecting cell sites to the MTSO. Lap Lee estimates that such line charges account for 10%-12% of revenues of a typical cellular firm. The Cellular Communications Service Industry (New York, Salomon Brothers Inc., July 1988), p.10.

[88] A large share of marketing expenditure takes the form of commissions paid to equipment retailers who sign up customers for some minimum period of service. Such agents are paid $200-$400 per new activation. Liebowitz, Gross and Buck, (Fall 1989), p. 9. These fees are generally partially passed on new customers in the form of subsidies for the purchase of new mobile units.

[89] At a 10% after tax rate of return an infinitely lived asset with a constant annual payment is worth ten times the annual payment.

Los Angeles population in 1991 gives a "per pop" value of $225. This is quite close to the $220 per pop market value estimated by Liebowitz, Gross and Buck.[90]

E. BENEFITS OF ADDITIONAL SPECTRUM

1. Case 1: Equal Division of Spectrum Between Two Existing Systems, No Price Reduction

In Section III we showed that discontinuing TV service on one of the 13 UHF stations in Los Angeles would release 18 megahertz of spectrum for cellular telephone service at most existing cell sites in the Los Angeles MSA.[91] The benefits, for the years 1992-2000, of dividing this spectrum equally between the two existing systems, with prices and output assumed to be unchanged, are summarized in table 6. Each firm was assumed to have 34 megahertz of spectrum and an equal number of subscribers. For this case we estimated that the present value of investment cost would be $45.3 million for each firm, or $90.5 million for the two, which is $118.2 million less than our estimate for the base case. The present value of total cost would also be $118.2 million less than for the base case, since non-investment costs were assumed to be independent of the quantity of spectrum. Likewise, the present value of before-tax profit would increase by the amount of the reduction in total cost.

With no change in output there would be no change in consumer surplus. Hence the increase in social welfare associated with the additional nine megahertz of spectrum per firm is just the increase in the producer surplus (before-tax profit), or $118.2 million. Table 6 also shows the increase in after-tax profits, $75.7 million, which can be interpreted as the change in market value, considering only the years 1992-2000.

Table 6 also shows that on a present value basis the total cost saving associated with the additional spectrum represents only 2.5% of base case total cost. The percentage is small because, while spectrum reduces investment cost by more than half, investment cost comprises only 4.4% of base case total cost.

a. Spectrum reduces the need to replace analog mobile radios. Some additional insights may be gleaned by comparing the spreadsheet generating the results of case 1 (table 7) to the base case spreadsheet (table 5). In our model, premature replacement of mobile radios accounted

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[90] Liebowitz, Gross and Buck, (Fall 1989) p. 5.

[91] That analysis also showed that spectrum would become available outside the MSA. If this additional spectrum were used for cellular, the benefits of a reallocation would exceed these estimates, which consider only the MSA. In section VI we extended the analysis to account for the value of spectrum outside the MSA.

Table 6

COMPARISON OF PRESENT VALUE OF COST, PROFITS AND CONSUMER SURPLUS OF SERVING CELLULAR SUBSCRIBERS IN LA 1992-2000 UNDER ALTERNATIVE ALLOCATIONS OF 18 MHZ OF ADDITIONAL SPECTRUM

	System A	System B	System C	Total	Difference Compared to Base Case
Base Case (Status quo)					
Spectrum (MHz)	25	25	0	50	
Share of new subscribers	50%	50%	0%		
PV Investment Cost ($ m)	104.4	104.4	0.0	208.8	
PV total cost ($ m)	2,373.4	2,373.4	0.0	4,746.7	
PV total revenue ($ m)	4,686.1	4,686.1	0.0	9,372.2	
PV total cost /PV total rev. ($m)				50.6%	
PV after tax profit ($ m)	1,480.1	1,480.1	0.0	2,960.3	
PV before tax profit ($ m)	2,312.7	2,312.7	0.0	4,625.4	
Case 1 (Equal division of spectrum between 2 existing systems, no price reduction)					
Spectrum (MHz)	34	34	0	68	
Share of new subscribers	50%	50%	0%		
PV Investment Cost ($ m)	45.3	45.3	0.0	90.5	-118.2
PV total cost ($ m)	2,314.2	2,314.2	0.0	4,628.5	-118.2
Cost saving/base case total cost					2.5%
PV after tax profit ($ m)	1,518.0	1,518.0	0.0	3,036.0	75.7
PV before tax profit ($ m)	2,371.8	2,371.8	0.0	4,743.7	118.2
PV consumer surplus ($ m)					0.0
PV consumer surplus + PV before tax profit (producer surplus) ($ m)					118.2
Case 2 (Equal division between 2 systems, 1.0% price reduction and output expansion)					
Spectrum (MHz)	34	34	0	68	
Share of new subscribers	50%	50%	0%		
PV Investment Cost ($ m)	46.2	46.2	0.0	92.5	-116.3
PV total cost ($ m)	2,338.6	2,338.6	0.0	4,677.1	-69.6
Cost saving/base case total cost					1.5%
PV after tax profit ($ m)	1,500.8	1,500.8	0.0	3,001.7	41.4
PV before tax profit ($ m)	2,345.0	2,345.0	0.0	4,690.1	64.6
PV consumer surplus ($ m)					94.2
PV consumer surplus + PV before tax profit (producer surplus) ($ m)					158.8

Case 3 (Third System, no price reduction and no output expansion)

Spectrum (MHz)	25	25	18	68	
Share of new subscribers	33%	33%	33%		
PV Investment Cost ($ m)	71.9	71.9	52.5	196.3	-12.4
PV total cost ($ m)	2,016.0	2,016.0	702.3	4,734.3	-12.4
Cost saving/base case total cost					0.3%
% cost increase over case 1				2.3%	
PV after tax profit ($ m)	1,287.9	1,287.9	379.0	2,954.9	-5.4
PV before tax profit ($ m)	2,012.4	2,012.4	613.1	4,637.9	12.4
PV consumer surplus ($ m)					0.0
PV consumer surplus + PV before tax profit (producer surplus) ($ m)					12.4

Case 4 (Third system, 3.5% price reduction and output expansion)

Spectrum (MHz)	25	25	18	68	
Share of new subscribers	33%	33%	33%		
PV Investment Cost ($ m)	77.9	77.9	56.3	212.0	3.2
PV total cost ($ m)	2,077.8	2,077.8	762.0	4,917.6	170.8
PV after tax profit ($ m)	1,224.4	1,224.4	374.7	2,823.5	-136.7
PV before tax profit ($ m)	1,913.1	1,913.1	610.9	4,437.2	-188.3
PV consumer surplus ($ m)					333.7
PV consumer surplus + PV before tax profit (producer surplus) ($ m)					145.4

Table 7

REVENUES, COST, AND PROFITS OF SERVING CELLULAR SUBSCRBIBERS IN LOS ANGELES 1992-2000
CASE 1: AN INCUMBENT OPERATOR WITH 34 MHZ, NO PRICE REDUCTION

	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
POPULATION (000s)	13,594	13,798	14,005	14,215	14,428	14,644	14,864	15,087	15,313	15,543
TOTAL CELLULAR MARKET										
Penetration rate	5.6%	6.6%	7.6%	8.6%	9.6%	10.6%	11.6%	12.6%	13.0%	13.0%
Subscribers year end (000s)	761	911	1,064	1,222	1,385	1,552	1,724	1,901	1,991	2,021
% growth		19.6%	16.9%	14.9%	13.3%	12.1%	11.1%	10.2%	4.7%	1.5%
INCUMBENT CELLULAR SYSTEM										
Subscribers										
Share of total additions		50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Share of total market	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Subscribers year end (000s)	381	455	532	611	693	776	862	950	995	1,010
Subscribers added (000s)		75	77	79	81	84	86	88	45	15
Average # subscribers (000s)		418	494	572	652	734	819	906	973	1,003
% growth in subscribers			16.9%	14.9%	13.3%	12.1%	11.1%	10.2%	4.7%	1.5%
Revenues										
Per subscriber/month ($)	125	120	115	110	105	100	95	90	85	80
Total annual revenues ($ m)		601.9	681.4	754.7	821.4	881.2	933.8	978.8	992.4	962.7
Pres. value total rev. ($ m)	4,686.1									
Cell sites										
Total	270	270	270	270	270	270	270	270	270	270
New		0	0	0	0	0	0	0	0	0
Channels										
Subscribers per voice channel	25	24.8	25.8	25.8	25.8	28.3	28.3	28.3	30	30
Total voice channels	15,225	18,360	20,627	23,691	26,843	27,426	30,463	33,586	33,586	33,677
Voice channels per sector	18.8	22.7	25.5	29.3	33.2	33.9	37.6	41.5	41.5	41.6
New voice channels		3,135	2,267	3,064	3,151	583	3,038	3,123	0	91
Total analog rf channels	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225

New analog rf channels		0	0	0	0	0	0	0	0	0
Total 3X digital rf channels		1,045	1,801	779	0	0	0	0	0	0
New 3X digital rf channels		1,045	756	-1,021	-779	0	0	0	0	0
Total 6X digital rf channels		0	0	1,021	1,936	2,033	2,540	3,060	3,060	3,075
New 6X digital rf channnels		0	0	1,021	915	97	506	520	0	15
Total rf channels in use	15,225	16,270	17,026	17,026	17,161	17,259	17,765	18,285	18,285	18,300
Unused rf chan. prev. period		5,481	4,436	3,680	3,680	3,545	3,448	2,941	2,421	2,421
Mobile radios										
Replacement mobile radios		0	0	0	0	0	0	0	0	0
Investment cost										
Cell sites ($ m)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RF channels ($ m)		15.7	11.3	5.1	6.6	1.9	10.1	10.4	0.0	0.3
Replacement mobile radios ($m)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Switch (MTSO) ($ m)		1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total ($ m)		16.7	11.3	5.1	6.6	1.9	10.1	10.4	0.0	0.3
Invest./ new subscriber ($)		223.2	147.5	64.6	81.3	23.2	117.8	117.8	0.0	20.2
Invest./ new sub./ mth. ($)		2.9	1.9	0.9	1.1	0.3	1.6	1.6	0.0	0.3
Pres. value total invest. ($m)	45.3									
PV invest./PV revenue	1.0%									
PV invest./PV total cost	2.0%									
Operating expenses										
Op. expenses per avg. sub. ($)		360	289	247	230	210	204	189	186	173
Total operating expenses ($ m)		150.5	142.7	141.2	149.9	154.2	167.1	171.3	181.0	173.5
% of revenue		25.0%	20.9%	18.7%	18.3%	17.5%	17.9%	17.5%	18.2%	18.0%
Admin. and gen. expenses										
G & A per avg. sub. ($)		600	567	386	293	238	204	174	157	140
Total G & A ($ m)		250.8	280.0	220.7	191.0	174.8	167.1	157.7	152.7	140.4
% of revenue		41.7%	41.1%	29.2%	23.3%	19.8%	17.9%	16.1%	15.4%	14.6%
Marketing expenses										
Marketing per new sub. ($)		600	550	500	450	400	400	400	400	400
Total marketing ($ m)		44.8	42.3	39.5	36.6	33.4	34.4	35.3	18.0	6.0
% of revenue		7.4%	6.2%	5.2%	4.5%	3.8%	3.7%	3.6%	1.8%	0.6%

Total cost										
Investment + all expenses ($m)		462.7	476.3	406.5	384.1	364.4	378.7	374.7	351.7	320.2
Total cost/total revenue		76.9%	69.9%	53.9%	46.8%	41.3%	40.6%	38.3%	35.4%	33.3%
Present value total cost ($ m)	2,314.2									
PV cost/PV revenue	49.4%									
Profit										
Pretax annual profit ($ m)		139.1	205.1	348.1	437.2	516.8	555.1	604.1	640.7	642.6
After tax annual profit ($ m)		89.0	131.3	222.8	279.8	330.8	355.3	386.6	410.1	411.2
PV pretax profit ($ m)	2,371.8									
PV after tax profit ($ m)	1,518.0									
Residual value in year 2001										
Ten times yr. 2000 profit ($ m)	4,112.4									
Present value residual value	1,585.5									
Market value in 1991 ($ m)										
PV profit + PV residual value	3,103.5									
Market value/population ($)	228									

for $96.6 million of investment cost for the base case. In contrast, in case 1 all new users well beyond the year 2000 can be accommodated on new spectrum without the need to replace existing mobile radios. Thus, avoiding the need to prematurely replace analog mobile units with digital ones accounts for most of the $118.2 million savings in investment costs for case 1.

A simple example provides the intuition behind this result: Assume an analog rf channel can be loaded with 25 subscribers and a digital rf channel can handle 75. Without additional spectrum, a system wishing to add 150 subscribers would need to add three digital channels and 225 (dual mode) digital mobile radios. Seventy-five of the digital mobile radios would be replacements for analog mobile units. In contrast, with additional spectrum, a system would need to add only two digital channels and 150 digital mobile units, saving the cost of one digital channel and 75 digital mobile units. We estimated that a digital base station radio providing three voice channels will cost $15,000. If it costs $650 to produce, distribute, and install a dual mode digital mobile radio, the cost of 75 such radios would be $48,750. This is over three times the savings associated with the reduced need for base station radios. On a per-new-subscriber basis, the additional spectrum would save $425 in investment costs. Of this, $325 would be associated with avoiding the need to scrap mobile units prematurely, and $100 with reducing the demand for base station radios.

b. Refinements. We will briefly discuss three refinements that may reduce the benefits of using spectrum from UHF television to provide additional cellular service. First, we did not account for research and development costs for cellular equipment operating on frequencies not currently allocated to cellular. Doug Collette of Advanced Mobile Communications[92] estimates the cost of developing and testing such equipment would be under one million dollars. If this is correct it is less than 1% of the social value of spectrum in cellular, and can safely be ignored in the analysis. If it were many times larger, it would have to be taken into account, and would reduce the benefit of reallocating spectrum from UHF TV to cellular.

Second, we assumed that manufacturing costs for equipment using newly allocated UHF spectrum would be the same as for equipment using frequencies already allocated to cellular. The cost penalty, if any, depends on the proximity of the new spectrum to existing cellular allocations, whether the mobile radios operating on the new frequencies are also able to operate on existing cellular frequencies, and the scale of production. According to Doug Collette,[93] mobile units designed to operate only on the new spectrum would cost no more to manufacture

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[92] Conversation May 17, 1990.

[93] Telephone conversations May 15 and May 17, 1990.

than those operating on existing cellular spectrum. He estimates a cost penalty of about 10% if the new mobiles operate on both the new and existing cellular spectrum and tune over a bandwidth range of about 15%-20%. In the worst case a mobile unit that could operate on either system would cost twice as much to manufacture as a standard mobile unit since it would be essentially two separate radios sharing a handset.[94] Thus, a more refined analysis might place different value on spectrum depending on frequency location. For example, channel 69, which is adjacent to the cellular band, might have a higher value than lower channels, other things being equal, since only minor modification of existing equipment would be needed.

Development and manufacturing costs might be minimized if a cellular system operating on reallocated UHF television spectrum could use off-the- shelf equipment developed for a large market abroad. One possibility is that equipment designed for the new European digital cellular standard, known as Global System for Mobile Communications (GSM), may be able to operate on the frequencies allocated to UHF television in the U.S. with little or no modification. If this were the case, an operator of a start-up third U.S. cellular system could benefit from the economies of scale from production for the large European market. The new entrant could also benefit from competition among vendors since GSM is an open standard that allows for mixing and matching of equipment from multiple vendors.

Third, we did not account for differences in usage among subscribers. A small percentage of subscribers may be responsible for a high percentage of total minutes of cellular usage during peak periods. If conversion from analog to digital mobile units is concentrated among such heavy users, fewer analog mobile units would need to be scrapped to expand capacity than we estimated for the cases where no additional spectrum is awarded to exiting operators. This would tend to reduce the gain from allocating additional spectrum to the existing cellular operators.

2. Case 2: Equal Division of Spectrum Between 2 Existing Systems, Price Reduction and Output Expansion

Existing operators might reduce prices if assigned additional spectrum because of the reduction in marginal cost. We analyzed this possibility under the assumption that each 1% reduction in prices during a period would increase the number of subscribers at the end of that period by 1%.[95]

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[94] Note that manufacturing costs represent only part of the total cost of providing an installed mobile unit. Other costs include distribution, retailing, and installation. Part of installation costs are the value of the customer's time and lost use of the vehicle while the unit is installed.

[95] Our model does not allow for the effect of price changes on usage of individual cellular subscribers, it only allows for the effect on the total number of customers.

We calculated the minimum price reduction for which the gain in consumer plus producer surplus from dividing 18 MHz of new spectrum evenly between two incumbent cellular operators would exceed the loss from taking a UHF TV station off the air. We found that slightly less than a 1% price reduction would be sufficient.[96] If cellular prices fell a full 1%, the gain in total surplus in cellular would be $159 million, which exceeds the social value of the loss of a UHF TV signal by $20 million. This is shown in table 6 as case 2.

The last column in table 6 compares each case to the base case. For case 2 the additional spectrum saves about $116 million in investment cost (present value in 1991 for the years 1992-2000). This is almost the same as the investment savings in case 1, despite the increased output. But the savings in total costs is only $69.6 million, where the difference reflects the non-investment costs associated with serving additional users. The increase in before-tax profits is $64.6 million, $5 million less than the savings in total cost. The source of this difference is a slight decline in total revenue, which is a consequence of our assumption that consumers do not respond instantly to price reductions.[97]

a. Calculating the gain in consumer surplus. Figure 8 helps illustrate our calculation of the gain in consumer surplus from reducing the price of cellular telephone service. The vertical axis represents the price of service and the horizontal axis the number of subscribers in the market (the total for all firms). The downward sloping demand curve shows the number of subscribers purchasing the service at each price. "P_1" is the initial price and "P_2" is the price after the assignment of additional spectrum to cellular operators. The gain to consumers from this price cut is approximately equal to the area A + B. Area A equals the price change times the initial consumption level, representing the amount of money consumers would save after the price cut if they continued to purchase the old amount of cellular service. This accounts for most of the gain to consumers from a price reduction. But the gain is somewhat greater than area A because at a lower price consumption would expand from Q_1 to Q_2 and the value to consumers

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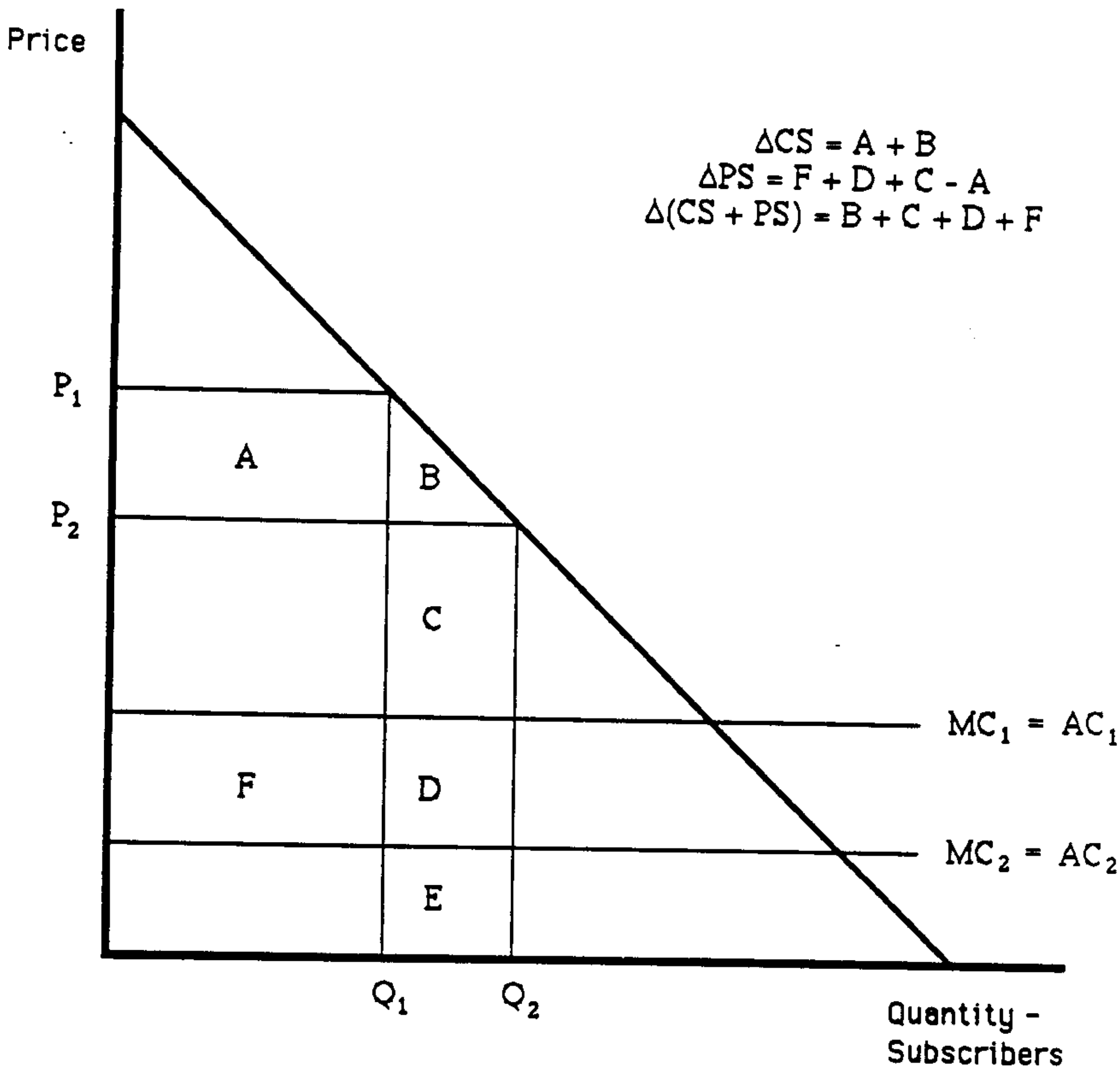
96 If we had assumed a price elasticity greater than unitary, an even smaller price reduction would be sufficient.

97 The number of subscribers at the end of each period is determined by a demand curve with a (constant) unitary price elasticity of demand. Revenues and consumer surplus are calculated based on the average of the number of subscribers at the beginning and the end of each period. It is only in the first period of a price change, however, that the effective price elasticity is less than one. For a 1% price reduction the average number of subscribers during the first period increases by slightly less than 1%, since the number of subscribers at the beginning of that period is unaffected by the price change. Since we calculate revenue based on the average number of subscribers, this assumption implies that a price reduction slightly reduces total revenue in the first period.

Figure 8

The Gain in Consumer plus Producer Surplus from Additional Spectrum with a Price Reduction



of this additional consumption exceeds the amount they pay for it by approximately area B.[98]

We calculated both the rectangular area A and triangular area B for each year between 1992-2000 and then found their present value in 1991. The calculations are shown in table 8. For a 1% price reduction the present values of areas A and B was $93.7 million and $.4 million respectively. Thus the area of the triangle was less than .5% that of the rectangle. Adding these areas together provides a total gain in consumer surplus of $94.2 million. Combined with the $64.6 million in producer surplus calculated above, we find a total gain in social welfare in case 2 of $158.8 million. This gain exceeds the estimated $139 million social loss from discontinuing TV service on a UHF station.

b. Understanding the welfare gain from output expansion. The modest expansion in output assumed in case 2 produced over $40 million more in consumer plus producer surplus than in case 1. In other words, an output expansion of slightly less than 1% increased social welfare by 34%. Figure 8 is helpful in understanding the source of this surprisingly large welfare gain. To simplify the exposition, we show the industry as having constant average and marginal cost. This is a reasonable approximation for the time period we examine since existing operators will be expanding capacity by installing digital radios at existing cell sites at an approximately constant average variable cost, and fixed costs are a relatively small component of total costs. AC_1 and MC_1, which are equal, represent the average and marginal cost for the industry in Los Angeles in the absence of additional spectrum (the base case). AC_2 and MC_2 represent the industry average and marginal cost with the addition of new spectrum (cases 1 and 2).

For case 1, the gain in producer surplus from additional spectrum is given by area F and equals $118.2 million. It is the reduction in average cost per subscriber (AC_1 - AC_2) times the initial number of subscribers (Q_1), which equals the reduction in total cost of serving the initial number of subscribers. There is no gain in consumer surplus.

Case 2 differs from case 1 in that it accounts for the welfare gain from output expansion. Figure 8 shows price falling from P_1 to P_2 and output expanding from Q_1 to Q_2, as a result of

[98] To see this suppose that each subscriber buys one unit of service. The demand curve can be thought of as ranking consumers according to the maximum amount they would pay for cellular service, with the highest valuations at the upper left of the curve and the lowest at the lower right. Total demand is given by the number of individuals whose valuation exceeds price. At price P_1 there are Q_1 subscribers and the Q1st is just indifferent between subscribing and doing without service. At price P_2 there are Q_2 subscribers and the Q2nd is just indifferent between subscribing and doing without service. At the new price, P_2, the Q1st subscriber is better off by P_1 - P_2. The Q_1+1st subscriber gains by a somewhat smaller amount, which is given by the distance between the height of the demand curve and P_2. The gain decreases as one moves down the demand curve toward the Q2nd subscriber. The total benefit to these new subscribers is approximated by the triangular area B. For a more formal analysis of why the area A + B approximates the amount that consumers would be willing to pay for the price reduction see Brown and Sibley, pp. 8-13

Table 8

CONSUMER SURPLUS FROM A 1% REDUCTION IN PRICE OF CELLULAR SERVICE

	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
POPULATION (000s)	13,594	13,798	14,005	14,215	14,428	14,644	14,864	15,087	15,313	15,543
TOTAL CELLULAR MARKET										
Without Entry										
Penetration rate	5.6%	6.6%	7.6%	8.6%	9.6%	10.6%	11.6%	12.6%	13.0%	13.0%
Subscribers year end (000s)	761	911	1,064	1,222	1,385	1,552	1,724	1,901	1,991	2,021
Average # subscribers (000s)		836	988	1,143	1,304	1,469	1,638	1,813	1,946	2,006
Price per subs./month ($)	125	120	115	110	105	100	95	90	85	80
Total annual revenues ($ m)		1,203.8	1,362.8	1,509.3	1,642.8	1,762.4	1,867.6	1,957.6	1,984.8	1,925.4
Pres. value total rev. ($ m)	9,372.2									
With Entry										
Penetration rate	5.6%	6.7%	7.7%	8.7%	9.7%	10.7%	11.7%	12.7%	13.1%	13.1%
Subscribers year end (000s)	761	920	1,075	1,235	1,399	1,568	1,742	1,920	2,011	2,041
Average # subscribers (000s)		841	997	1,155	1,317	1,484	1,655	1,831	1,966	2,026
Price per subs./month ($)	125	118.8	113.85	108.9	103.95	99	94.05	89.1	84.15	79.2
Total annual revenues ($ m)		1,198.3	1,362.8	1,509.3	1,642.8	1,762.4	1,867.6	1,957.6	1,984.8	1,925.4
Pres. value total rev. ($ m)	9,367.2									
Difference										
Average # subscribers (000s)		5	10	12	13	15	17	18	20	20
Price per subs./month ($)		1.2	1.15	1.1	1.05	1	0.95	0.9	0.85	0.8
Consumer Surplus ($ m)	PV	Annual								
Triangle	0.4	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rectangle	93.7	12.0	13.6	15.1	16.4	17.6	18.7	19.6	19.8	19.3
Total	94.2	12.1	13.7	15.2	16.5	17.7	18.8	19.7	19.9	19.4

ASSUMPTIONS:

Discount rate	10%
Price elaticity of demand	1%

assigning additional spectrum to existing carriers. As discussed above, the area A + B represents the gain in consumer surplus for case 2.

The gain in producer surplus for case 2 is equal to area F + C + D - A. As in case 1, area F is the cost saving for producing the initial output. Area A is the reduction in amount paid by consumers for the old output level as a result of the price cut and therefore represents an equivalent loss in revenue for producers. Area C + D is the gain in profit associated with the new output. To see this observe that area C + D + E equals the additional revenue gained from the new subscribers since it is the new price (P_2) times the number of new subscribers (Q_2 -Q_1). And E, the area under the new marginal cost curve from Q_1 to Q_2, is the cost of providing service to these new subscribers.[99] Subtracting the cost of serving the new subscribers, E, from the revenue they generate, C + D + E, leaves the gain in profit from serving them, C + D.

The gain in consumer plus producer surplus for case 2 is given by the sum of areas A + B and F + C + D - A. This equals F + B + C + D, since the gain to consumers represented by area A is an equivalent loss to producers.[100]

Comparing case 2 to case 1, we see that the gain in welfare due to output expansion is represented by area B + C + D, and equals $40.6 million. Since area B, the gain to consumers associated with output expansion, equals only $.4 million, area C + D, the gain to producers due to output expansion, equals $40.2 million. This is the primary source of the welfare gain due to output expansion.

Area C + D is a consequence of the gap between price and marginal cost, which in turn is a result of entry barriers currently limiting provision of cellular service to two firms. This area would not exist in a competitive industry, in which price always equals marginal cost. This is illustrated in figure 9. P_1 is the initial price, which is equal to the initial marginal and average cost, MC_1 and AC_1. With additional spectrum, marginal and average cost fall to MC_2 and AC_2, and price falls the same amount to P_2. The total gain in welfare is area A + B. It is all consumer surplus. There is no gain in producer surplus. Area A is both the reduction in the

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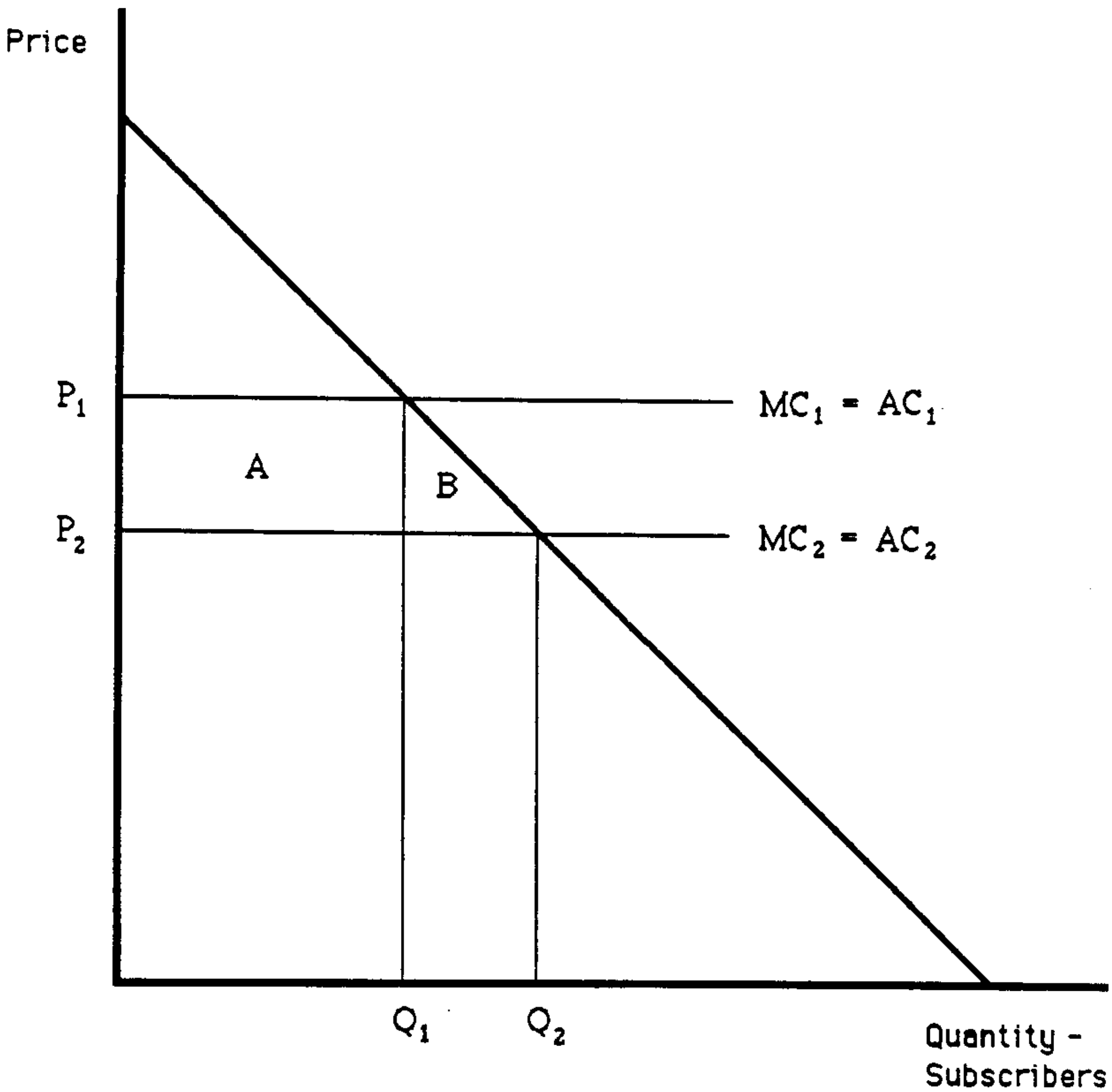
[99] The height of the marginal cost curve gives the cost of providing service for an additional subscriber, so the area under the curve from Q_1 to Q_2 is the cost of serving these additional subscribers.

[100] There is another way to derive this result. The benefits from allocating additional spectrum to cellular telephone can be broken down into the following two components: (1) The reduction in the cost of producing the initial output. This is given by area F in figure 8. (2) The value to consumers of the additional output produced because more spectrum has been allocated to mobile telephone services. This is the maximum amount consumers would be willing to pay for the additional output, and is approximated by the area under the demand curve between the old and new output. This is given by area B + C + D + E in figure 8. Subtracting area E, the cost of producing the new output, from the sum of benefits (1) and (2) gives a net benefit of F + B + C + D, the same result as derived in the text.

Figure 9

Welfare Gain When Price Equals Marginal Cost



amount paid by consumers to purchase the initial level of output and the cost savings to producers to provide that level of output. It corresponds to both areas A and F in figure 8. Area B is the total gain in social welfare due to output expansion, and it all accrues to consumers.

3. Case 3: Third System With No Price Reduction

For case 3 we assumed that the new spectrum is allocated to a third system, and that new entry has no effect on price or total output. We also assumed that each of the three systems attracts an equal share of new subscribers. The results for this case are summarized in table 6, along with the other cases. From this table one can see that the present value of both investment and total cost are $12.4 million less than for the base case. Since total revenue is unchanged when price and quantity are unchanged, this cost reduction is also the increase in before-tax profit. Moreover, since there is no gain in consumer surplus when price and output are fixed, the gain in consumer plus producer surplus for case 3 is also $12.4 million.

Both investment and total cost, however, are $105.8 million greater than for case 1 (equal division of spectrum between the existing systems). This represents only a 2.3% increase in total cost, but would be a 116.9% increase in investment cost. The cost penalty of creating a third system instead of allocating spectrum to existing systems (case 3 compared to case 1) can be broken down into four underlying components:[101]

(1) Additional cell sites. A third system must build new cell sites, while existing systems could use existing sites. It would not need nearly as many total cell sites as the existing systems, however, since it can rely on digital technology, while the existing systems were developed based on analog technology. We estimated that a third system capturing one-third of new subscribers would need only 16 cell sites in 1992 and 52 sites in 2000. The present value of these additional sites is $22.3 million, which is 21% of the excess cost over case 1. (2) Additional base station radios (rf channels). If the existing systems are not allocated additional spectrum they will expand capacity by replacing analog base station radios with digital ones. Some of the added capacity of the new digital radios would go to replacing the lost output of the scrapped analog radios. Allocating spectrum to a third system would thus increase the number of rf radios needed to meet total industry demand. The present value of these additional RF radios is $16.5 million, or 16% of the investment cost penalty. (3) Replacement mobile radios. Without additional spectrum existing systems will also need to replace the analog mobile units associated with the analog base station radios it removes. If the new spectrum were allocated to the existing systems instead of to a third system, they would not need to do so. In our model the cost of replacing

[101] There may be start-up costs in addition to these which we did not consider.

these mobile units operating on the existing systems would be about $66 million. This represents 62% of the added investment cost. (4) Additional mobile telephone switch. A third system would need to duplicate the existing mobile telephone switching offices. We estimated this cost at $1 million, or 1% of the added investment cost associated with creating a third system.

This cost penalty would be smaller if the third system captured a greater share of the new subscribers than we assumed, because in our model, the third system, with vacant spectrum, has a lower marginal cost than the incumbents, whose rf channels are all occupied. Looking at case 3 in table 6, one can see that the present value of investment cost of serving the same number of new subscribers (one-third of the total) is lower for the third system than for an incumbent -- $52.5 million versus $71.9 million. And in our model one does not need to examine non-investment costs because we assumed that they are the same per new subscriber for all systems. Moreover, comparing tables 9 and 10, one can see that in every year the investment cost per new subscriber is less for the third system than for an incumbent.[102]

This result was derived under the assumption that a new entrant can add capacity in increments just sufficient to meet total demand. This may not be the case, however. If demand increases uniformly across cell sites and existing cell locations are fixed, it may be necessary to split all cells when demand reaches system capacity. This would result in lower average loading of the system and thus higher costs per user than under our assumption. An upper bound on the increase in investment cost due to such lumpiness can be estimated by assuming that all investment needed through the year 2000 must be made in 1991. Table 9 shows that a third system under the assumptions of case 3 would start with 16 cell sites in 1992 and have 52 cell sites in 2000. The present discounted value of this investment would be $22.3 million, assuming a cost of $600,000 per cell site and a 10% discount rate. If all 52 cell sites were instead installed in 1991 the cost would be $31.2 million. Similarly, if all base station radios needed in 2000 were installed in 1991 the cost would be $42 million. This is $12.7 million more than our estimate of the present value of gradually installing RF channels as shown in table 9. Adding this to the $8.9 million additional cell site costs produces an increase in total investment of $21.6 million or about 42%. This implies a total system investment of $74.1 million (including $.9 million present value of switch investment), which would represent about 10% of total cost, instead of the 7.5% that we estimated assuming that cell site investment can be made in small increments. Accounting for the lumpiness of cell investment would not, however, affect our basic result, developed later in the paper, that additional entry would be socially beneficial, since

102 Another way to reduce the total cost of serving all subscribers while still achieving the benefits of competition might be to assign some of the new spectrum to existing systems and some to a third system. We did not calculate the effects of this approach, however.

Table 9

REVENUES, COST, AND PROFITS OF SERVING CELLULAR SUBSCRBIBERS IN LOS ANGELES 1992-2000
CASE 3: THIRD SYSTEM WITH 18 MHZ AND NO PRICE REDUCTION

	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
POPULATION (000s)	13,594	13,798	14,005	14,215	14,428	14,644	14,864	15,087	15,313	15,543
TOTAL CELLULAR MARKET										
Penetration rate	5.6%	6.6%	7.6%	8.6%	9.6%	10.6%	11.6%	12.6%	13.0%	13.0%
Subscribers year end (000s)	761	911	1,064	1,222	1,385	1,552	1,724	1,901	1,991	2,021
% growth		19.6%	16.9%	14.9%	13.3%	12.1%	11.1%	10.2%	4.7%	1.5%
THIRD CELLULAR SYSTEM										
Subscribers										
Share of total additions		33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%
Share of total market		5.5%	9.5%	12.6%	15.0%	17.0%	18.6%	20.0%	20.6%	20.8%
Subscribers year end (000s)		50	101	154	208	264	321	380	410	420
Subscribers added (000s)		50	51	53	54	56	57	59	30	10
Average # subscribers (000s)		25	75	127	181	236	292	350	395	415
% growth in subscribers			102.9%	52.2%	35.3%	26.8%	21.7%	18.4%	7.9%	2.4%
Revenues										
Per subscriber/month ($)	125	120	115	110	105	100	95	90	85	80
Total annual revenues ($ m)		35.9	104.1	168.2	227.9	283.0	333.3	378.5	402.8	398.2
Pres. value total rev. ($ m)	1,315.4									
Cell sites										
Total		16	28	28	28	33	40	47	50	52
New		16	11	0	0	5	6	7	4	1
Channels										
Subscribers per voice channel		25	30	30	32	32.7	33.3	33.3	33.3	33.3
Total voice channels		1,992	3,368	5,125	6,498	8,064	9,639	11,409	12,307	12,606
New voice channels		1,992	1,376	1,757	1,374	1,565	1,576	1,769	899	299
Voice channels per sector		40.6	40.6	61.8	78.4	81.3	81.3	81.3	81.3	81.3

Total 3X digital rf channels		664	1,123	537	79	0	0	0	0	0
New 3X digital rf channels		664	459	-586	-458	-79	0	0	0	0
Total 6X digital rf channels		0	0	586	1,043	1,344	1,607	1,901	2,051	2,101
New 6X digital rf channels		0	0	586	458	300	263	295	150	50
Investment cost										
Cell sites ($ m)		9.8	6.8	0.0	0.0	3.3	3.9	4.4	2.2	0.7
RF channels ($ m)		10.0	6.9	2.9	2.3	4.8	5.3	5.9	3.0	1.0
Switch (MTSO) ($ m)		1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total ($ m)		20.8	13.7	2.9	2.3	8.1	9.1	10.3	5.2	1.7
Invest./ new subscriber ($)		417.0	266.5	55.6	42.2	145.2	159.3	174.0	174.0	174.0
Invest./ new sub./ mth. ($)		5.5	3.5	0.7	0.6	1.9	2.1	2.3	2.3	2.3
Pres. value total invest. ($m)	52.5									
PV invest./PV revenue	4.0%									
PV invest./PV total cost	7.5%									
Operating expenses										
Op. expenses per avg. sub. ($)		360	289	247	230	210	204	189	186	173
Total operating expenses ($ m)		9.0	21.8	31.5	41.6	49.5	59.6	66.2	73.4	71.8
% of revenue		25.0%	20.9%	18.7%	18.3%	17.5%	17.9%	17.5%	18.2%	18.0%
Admin. and gen. expenses										
G & A per avg. sub. ($)		600	567	386	293	238	204	174	157	140
Total G & A ($ m)		14.9	42.8	49.2	53.0	56.1	59.6	61.0	62.0	58.1
% of revenue		41.7%	41.1%	29.2%	23.3%	19.8%	17.9%	16.1%	15.4%	14.6%
Marketing expenses										
Marketing per new sub. ($)		600	550	500	450	400	400	400	400	400
Total marketing ($ m)		29.9	28.2	26.4	24.4	22.3	22.9	23.6	12.0	4.0
% of revenue		83.3%	27.1%	15.7%	10.7%	7.9%	6.9%	6.2%	3.0%	1.0%
Total cost										
Investment + all expenses ($m)		74.5	106.4	109.9	121.3	136.0	151.3	161.0	152.6	135.5
Total cost/total revenue		207.9%	102.2%	65.4%	53.2%	48.1%	45.4%	42.5%	37.9%	34.0%
Present value total cost ($ m)	702.3									
PV cost/PV revenue	53.4%									

Profit										
Pretax annual profit ($ m)		-38.7	-2.3	58.2	106.6	146.9	181.9	217.5	250.1	262.7
After tax annual profit ($ m)		-38.7	-2.3	37.3	68.2	94.0	116.4	139.2	160.1	168.1
PV pretax profit ($ m)	613.1									
PV after tax profit ($ m)	379.0									
Residual value in year 2001										
Ten times yr. 2000 profit ($ m)	1,681.1									
Present value residual value	648.1									
Market value in 1991 ($ m)										
PV profit + PV residual value	1,027.1									
Market value/population ($)	75.6									

Table 10

REVENUES, COST, AND PROFITS OF SERVING CELLULAR SUBSCRBIBERS IN LOS ANGELES 1992-2000
CASE 3: AN INCUMBENT OPERATOR WITH 25 MHZ IN THE PRESENCE OF A THIRD SYSTEM, NO PRICE REDUCTION

	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
POPULATION (000s)	13,594	13,798	14,005	14,215	14,428	14,644	14,864	15,087	15,313	15,543
TOTAL CELLULAR MARKET										
Penetration rate	5.6%	6.6%	7.6%	8.6%	9.6%	10.6%	11.6%	12.6%	13.0%	13.0%
Subscribers year end (000s)	761	911	1,064	1,222	1,385	1,552	1,724	1,901	1,991	2,021
% growth		19.6%	16.9%	14.9%	13.3%	12.1%	11.1%	10.2%	4.7%	1.5%
INCUMBENT CELLULAR SYSTEM										
Subscribers										
Share of total additions		33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%
Share of total market	50.0%	47.3%	45.3%	43.7%	42.5%	41.5%	40.7%	40.0%	39.7%	39.6%
Subscribers year end (000s)	381	430	482	534	589	644	702	761	790	800
Subscribers added (000s)		50	51	53	54	56	57	59	30	10
Average # subscribers (000s)		406	456	508	561	616	673	731	775	795
% growth in subscribers			11.9%	10.9%	10.1%	9.5%	8.9%	8.4%	3.9%	1.3%
Revenues										
Per subscriber/month ($)	125	120	115	110	105	100	95	90	85	80
Total annual revenues ($ m)		584.0	629.3	670.6	707.5	739.7	767.2	789.6	791.0	763.6
Pres. value total rev. ($ m)	4,028.4									
Cell sites										
Total	270	270	270	270	270	270	270	270	270	270
New		0	0	0	0	0	0	0	0	0
Channels										
Subscribers per voice channel	25	24.8	25.8	25.8	25.8	25.8	28.3	28.3	28.3	28.3
Total voice channels	15,225	17,356	18,669	20,712	22,813	24,973	24,973	26,874	27,931	28,283
Voice channels per sector	18.8	21.4	23.1	25.6	28.2	30.9	30.9	33.2	34.5	34.9
New voice channels		2,131	1,313	2,043	2,101	2,160	0	1,901	1,057	352
Total analog rf channels	15,225	14,160	13,503	13,503	13,503	13,275	13,275	12,895	12,684	12,614
New analog rf channels		-1,065	-657	0	0	-228	0	-380	-211	-70
Total 3X digital rf channels		1,065	1,722	1,041	341	0	0	0	0	0
New 3X digital rf channels		1,065	657	-681	-700	-341	0	0	0	0

Total 6X digital rf channels		0	0	681	1,381	1,950	1,950	2,330	2,541	2,612
New 6X digital rf channels		0	0	681	700	568	0	380	211	70
Total rf channels in use	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225	15,225
Unused rf chan. prev. period		0	0	0	0	0	0	0	0	0
Mobile radios										
Replacement mobile radios		26,422	16,940	0	0	5,874	0	10,757	5,985	1,991
Investment cost										
Cell sites ($ m)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RF channels ($ m)		16.0	9.8	3.4	3.5	6.3	0.0	7.6	4.2	1.4
Replacement mobile radios ($m)		17.2	11.0	0.0	0.0	3.8	0.0	7.0	3.9	1.3
Switch (MTSO) ($ m)		1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total ($ m)		34.2	20.9	3.4	3.5	10.1	0.0	14.6	8.1	2.7
Invest./ new subscriber ($)		685.9	407.1	64.6	64.6	180.7	0.0	247.7	271.3	271.3
Invest./ new sub./ mth. ($)		9.1	5.4	0.9	0.9	2.4	0.0	3.3	3.6	3.6
Pres. value total invest. ($m)	71.9									
PV invest./PV revenue	1.8%									
PV invest./PV total cost	3.6%									
Operating expenses										
Op. expenses per avg. sub. ($)		360	289	247	230	210	204	189	186	173
Total operating expenses ($ m)		146.0	131.8	125.5	129.1	129.5	137.3	138.2	144.2	137.6
% of revenue		25.0%	20.9%	18.7%	18.3%	17.5%	17.9%	17.5%	18.2%	18.0%
Admin. and gen. expenses										
G & A per avg. sub. ($)		600	567	386	293	238	204	174	157	140
Total G & A ($ m)		243.3	258.6	196.1	164.5	146.7	137.3	127.2	121.8	111.4
% of revenue		41.7%	41.1%	29.2%	23.3%	19.8%	17.9%	16.1%	15.4%	14.6%
Marketing expenses										
Marketing per new sub. ($)		600	550	500	450	400	400	400	400	400
Total marketing ($ m)		29.9	28.2	26.4	24.4	22.3	22.9	23.6	12.0	4.0
% of revenue		5.1%	4.5%	3.9%	3.4%	3.0%	3.0%	3.0%	1.5%	0.5%
Total cost										
Investment + all expenses ($m)		453.3	439.4	351.3	321.5	308.5	297.5	303.5	286.1	255.7
Total cost/total revenue		77.6%	69.8%	52.4%	45.5%	41.7%	38.8%	38.4%	36.2%	33.5%
Present value total cost ($ m)	2,016.0									
PV cost/PV revenue	50.0%									

Profit										
Pretax annual profit ($ m)		130.6	189.9	319.2	385.9	431.2	469.7	486.0	504.9	508.0
After tax annual profit ($ m)		83.6	121.6	204.3	247.0	276.0	300.6	311.1	323.1	325.1
PV pretax profit ($ m)	2,012.4									
PV after tax profit ($ m)	1,287.9									
Residual value in year 2001										
Ten times yr. 2000 profit ($ m)	3,251.0									
Present value residual value	1,253.4									
Market value in 1991 ($ m)										
PV profit + PV residual value	2,541.3									
Market value/population ($)	187									

there still would be an ample margin for welfare enhancing price reductions.

We estimated the amount a third system would be willing to pay to enter the market as the present value of its after-tax profit. Considering just the years 1992-2000, we found this to be $379 million for case 3. This gain does not, however, match the total loss to the incumbents, falling short by about $5.4 million.

4. Case 4: Third System With Price Reduction and Output Expansion

Case 4 is the most interesting from a policy perspective. Assigning spectrum to a new system would almost surely result in lower prices and expanded output. The essential elements of this case are contained in the two previous cases. In case 3 we saw that there is a cost penalty associated with assigning spectrum to a third system. And in case 2 we saw that a modest reduction in price can generate a large gain in social welfare.

Combining these elements in case 4 brings out a classic tradeoff associated with entry into industries that exhibit some economies of scale: Entry is likely to result in lower prices while at the same time raising the cost of producing a given level of industry output. Unless economies of scale are very great, which they do not appear to be in this case, the gain in welfare associated with lower prices and expanded output (as well as the benefits of increased innovation spurred by competition) is likely to exceed the loss associated with increased production costs.

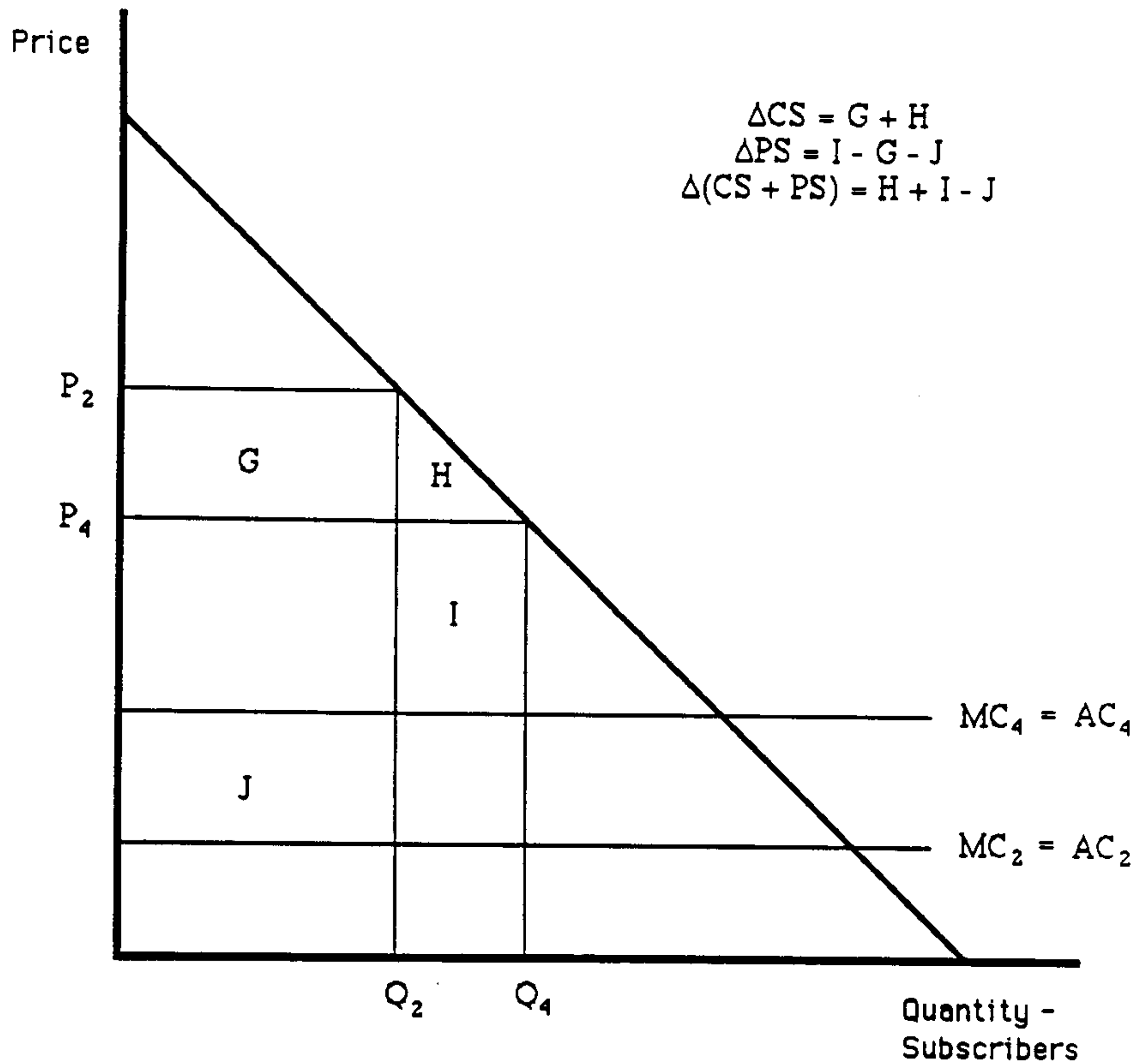
a. Minimum price reduction to justify a reallocation. In our model, entry need only result in about a 3.5% price reduction for the benefits of a reallocation to exceed the costs. This price reduction is approximately 2.5 percentage points greater than the minimum required for a reallocation to existing cellular operators to be socially beneficial (case 2) -- a small difference relative to the likely price reductions from introducing a third competitor.

The welfare tradeoff between lower prices and higher costs is illustrated in figure 10. The downward sloping curve shows market demand. P_2 and Q_2 are the market price and number of subscribers under case 2, in which the spectrum is allocated to the existing operators. AC_2 and MC_2 are the industry average cost and marginal cost for this case. If the additional spectrum is instead allocated to a third system, as in case 4, the market price will fall to P_4 and industry average and marginal cost will increase to AC_4 and MC_4.[103] The gain in consumer surplus from the price reduction is given by area G + H. The change in producer surplus is given by area I - G - J. The sum of consumer and producer surplus is thus represented by area H + I -

[103] The cost curves in the diagram do not correspond precisely to those implied by our model, but are simplified for the sake of illustration.

Figure 10

The Welfare Tradeoff from Allocating Spectrum to a Third System



J. Area J represents the cost increase due to entry. Area H + I gives the welfare benefit of output expansion due to added competition. If area H + I exceeds area J, welfare will be greater allocating the spectrum to a new entrant than to the incumbents. The less competitive the market absent new entry, and hence the larger the gap between price and marginal cost, the larger area I will be and the more likely that entry will increase welfare, other things equal.

The results of case 4 are summarized in table 6. Given our assumption of (approximately) unitary demand elasticity, a reduction in prices by all firms would reduce the present value of profits. With unitary demand elasticity, total revenue would remain the same with a price reduction, but profits would fall because costs would be greater with increased output. Before-tax profits for case 4 would be \$188.3 million less than for the base case, and \$200.7 million less than case 3 (a third system without a price reduction). Total market after-tax profits would be down as well. But the rewards to a new entrant would still remain large. Just considering the years 1992-2000, the present value of after-tax profits for a third system would be \$374.7 million.

The 3.5% price cut in case 4 would increase the present value of consumer surplus by \$333.7 million compared to the base case (as well as to cases 1 and 3). Adding this to the \$188.3 million reduction in pre-tax profits provides an increase of \$145.4 million in the present value of consumer plus producer surplus relative to the base case.

b. Likely price reduction. Theoretical models of oligopoly pricing can provide some insights into the likely price reduction as a result of entry of a third cellular competitor. Unfortunately, the state of knowledge about noncooperative (non collusive) oligopoly behavior is quite rudimentary. While there are many well developed models, there is no consensus among economists on which is best.[104]

We will use the Cournot model, one of the oldest and simplest models, to illustrate the effect on price of increasing the number of firms in a market from two to three.[105] As with other models of noncooperative oligopoly, it predicts the monopoly equilibrium when there is a single firm and the competitive equilibrium when there are large numbers of firms. With small numbers of firms it predicts a price lower than under monopoly, but greater than under competition.

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[104] See Dennis Carlton and Jeffrey Perloff, Modern Industrial Organization (Glenview, Illinois: Scott, Foresman and Company, 1990), pp. 258-310 for a discussion of noncooperative oligopoly.

[105] We are indebted to Gerry Faulhaber for suggesting the following illustration.

It can be shown that in the Cournot equilibrium in a market with n identical firms, the following condition must hold true for each firm:

$$\frac{P-MC}{P} = \frac{1}{ne},$$

where P is the market price, MC is the marginal cost of producing another unit of output, n is the number of firms and e is the market elasticity of demand.[106] The left hand side of the equation is the markup of price over marginal cost relative to price. This ratio is often referred to as the Lerner index of market power or the price-cost margin.[107] When price equals marginal cost, as under perfect competition, the ratio equals zero, and when there is a single profit-maximizing firm it equals 1/e.

To apply this single-period model to the cellular market we estimated the left hand side of the equation by the present value of total revenue minus the present value of total cost divided by the present value of total revenue.[108] For the base case of two cellular firms this ratio (the Lerner index) is equal to .5. (See table 6.) With two firms, n equals 2 in the equation above, so the price elasticity of market demand, e, must be 1 for the firms to be in a Cournot equilibrium, which is what we assumed in analyzing the effects of price reductions (cases 2 and 4).

With three firms in the market, n equals 3, and assuming a constant unitary elasticity of demand, the left hand side of the equation (the Lerner index) must equal 1/3 in the Cournot equilibrium. Assuming a constant marginal cost (which equals average cost) this implies that price will be 25% lower with three firms than with two.[109]

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[106] Carlton and Perloff, p. 304. This is also shown by Jean Tirole, Industrial Organization (Cambridge, Mass.: The MIT Press, 1988), p. 219.

[107] Carlton and Perloff, p. 102.

[108] Thus we used average cost instead of marginal cost:

$$\frac{TR-TC}{TR} = \frac{P*Q-AC*Q}{P*Q} = \frac{P-AC}{P},$$

where TR is total revenue, TC is total cost, P is price, Q is quantity, and AC is average cost.

[109] With two firms price was 2*MC. With three firms price was 1.5*MC since

$$\frac{P-MC}{P} = \frac{1}{3}.$$

Assuming MC remains unchanged, the change in price as a fraction of the old price is:

$$\frac{P_0-P_1}{P_0} = \frac{2*MC-1.5*MC}{2*MC} = .25.$$

In addition to the predictions of theoretical models there is some empirical evidence that entry of a third firm causes a significant reduction in prices.[110] John Kwoka, in a study of five manufacturing industries, found that "a sufficiently large third firm causes industry margins to fall by 13 or 14 percentage points."[111] If, as we calculated, the price-cost margin is 50% with two cellular operators, Kwoka's evidence suggests that with three firms the margin would be about 36%. This implies that price must fall about 22%, which is close to the amount predicted by the simple theoretical model.[112]

If the entry of a third system (with 18 MHz) resulted in a 25% price reduction, we estimated that the present value of consumer plus producer surplus (for the years 1992-2000) would be $922 million greater than in the base case. This gain far exceeds the loss of $139 million in social value from taking a UHF TV station off the air. Moreover, a third operator would have an incentive to enter the market, since the present value of after-tax profit (for the years 1992-2000) would be $253 million, which exceeds the $20 million present value of after-tax profits of the UHF TV station.

F. COMPARISON OF SPECTRUM VALUES IN CELLULAR TELEPHONE AND UHF TV BROADCASTING

Table 11 summarizes our findings. It shows both the social value (change in consumer plus producer surplus) and the market value (change in after-tax profits) of spectrum used in providing UHF TV and cellular telephone services. All estimates are the present discounted value in 1991 of annual values from 1992 to 2000. The UHF TV estimates, which were developed in section IV of the paper, are for a station covering downtown Los Angeles. The cellular telephone estimates are based on our finding in section III that discontinuing UHF TV service on one such channel while protecting ATV allotments would make available 18 megahertz of spectrum for cellular use throughout most of the metropolitan area.

We estimated the value of spectrum both for existing operators and for a third cellular system. We assumed that if the spectrum is assigned to existing operators, it is divided evenly (nine megahertz to each firm). This division provides the highest total social and private value

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110 But, as in the theoretical literature, there is no consensus in the empirical literature on the relationship between the number of firms and price-cost margins. See Carlton and Perloff, pp. 375-377

111 John Kwoka, "The Effect of Market Share Distribution on Industry Performance," The Review of Economics and Statistics, LXI (February, 1979), 107.

112 Entry of close substitutes to cellular would diminish the benefit of reallocating a UHF TV channel to cellular. While a fourth or fifth competitor using spectrum reallocated from UHF TV would likely result in further price reductions and output expansion, the benefits would be smaller than those associated with the entry of a third competitor.

Table 11

ESTIMATED VALUE OF 18 MHZ OF SPECTRUM OCCUPIED BY A UHF TV CHANNEL IN LOS ANGELES

Present Discounted Value in 1991 of Annual Values 1992-2000
($ millions)

	SOCIAL VALUE (Consumer plus producer surplus)	MARKET VALUE (After tax profit)
UHF TV	139	20
CELLULAR TELEPHONE		
Existing Operators		
No price reduction	118	76
1% price reduction	159	41
Third System		
No price reduction	12	379
3.5% price reduction	145	375
5% price reduction	202	372
10% price reduction	388	357
25% price reduction	922	253
39% price reduction	1,385	28

because the marginal benefit of spectrum diminishes as more is allocated to a firm, and the two firms are assumed to be identical. If spectrum is assigned to a third cellular system, we assumed that new subscribers are equally distributed among the three systems, but that subscribers of the existing systems do not migrate to the new entrant.

For each case, we first calculated the social and market values assuming no price reductions and hence no output expansion. If there is no output expansion, there is no change in consumer surplus. In this case, the social value of additional spectrum is just the change in producer surplus, which equals the reduction in the cost of providing the level of output that would prevail absent the additional spectrum. That output is assumed to grow rapidly each year but, for the no-price-reduction case, does not depend on the amount of spectrum allocated to cellular.

With no price reduction, we found that the spectrum made available by discontinuing television service on a UHF station in Los Angeles would have a social value of about $118 million if assigned to the existing cellular operators. This is less than the $139 million social value if the spectrum were used to provide UHF television service. Thus for this unlikely case, reallocating spectrum from UHF television to cellular would reduce consumer plus producer surplus.

For this same case, we estimated that the additional spectrum would increase the after-tax profits of existing operators by $76 million. This is the most they would be willing to pay for the spectrum currently used to provide a UHF television channel, assuming that only they are eligible to use it for cellular. Since this exceeds the $20 million market value of the spectrum used in providing UHF television, existing cellular operators would have the incentive to purchase the right to use the spectrum.

While the no-price-reduction case is helpful in illustrating the benefits of spectrum in reducing costs, it is unrealistic to assume that new entry would not lead to price reductions. Even existing operators might have an incentive to reduce prices if assigned additional spectrum because of the reduction in marginal cost. In making these calculations we assumed that all operators would cut their prices by the same amount and that output would expand by the approximately the same percentage as price falls.

If the spectrum were assigned to existing operators, a price reduction of slightly less than 1% would be needed for the gain in consumer plus producer surplus in cellular to exceed the loss in UHF television. If cellular prices would fall a full 1%, the gain in cellular would be $159 million, which exceeds the $139 million social value of the loss of a UHF television signal.

Existing operators would pay no more than $41 million to use this spectrum if they expected the reallocation to cause prices to fall 1%. A price cut would reduce their profits compared to the previous case because, given our assumption about demand elasticity, total revenue would stay about the same, but costs would increase with the increase in total output. While it would not be in the collective interest of the existing firms to make this price reduction, acting non-cooperatively they might do so.

Table 11 also shows the social and market value of spectrum assigned to a third cellular system for price reductions ranging from zero to 39%. With no price reduction, a reallocation of spectrum from UHF television to a third cellular system would result in an even greater net social loss than if the spectrum were assigned to the existing operators. Without a price reduction, the spectrum assigned to a third operator would have a social value of only $12 million, which would be considerably less than the $139 million social value if it were used in providing television service.

The market value of the spectrum, however, would be considerably greater if a third cellular system were permitted to bid. In the unlikely event that prices would not fall as a result of entry, we estimated that the right to operate a third cellular system in Los Angeles from 1992 to 2000 would be worth $379 million. This is far greater than the private value of spectrum used in providing UHF television.

Of course, if a third cellular provider entered the market we would not expect prices to remain unchanged. Even if prices fell only 3.5%, there would be a net social gain -- $6 million, assuming a UHF television station in Los Angeles would occupy 18 MHz of cellular spectrum. But, our simple theoretical model of oligopoly pricing and some empirical evidence from other highly concentrated markets suggest that entry by a third system would cause cellular prices to fall approximately 25%. In this case, such entry would increase the present value of consumer plus producer surplus in the Los Angeles cellular market by $922 million. This gain would far exceed the loss of $139 million in social value from taking a UHF television station off the air. Thus, the net social gain would be $783 million. Moreover, a third operator would have an incentive to enter the market since the present value of after tax profit would be $253 million, which exceeds the $20 million present value of after tax profits of the UHF television station.

VI. EXTENSIONS

We carried out a number of extensions and refinements of our analysis. Four most germane to our policy recommendations are discussed below.

A. VALUE OF DIFFERENT AMOUNTS OF SPECTRUM IN PROVIDING CELLULAR SERVICE

In chapter V we assumed that taking a UHF television station off the air would release 18 megahertz of spectrum for cellular telephone service. We focused on this case because 18 megahertz is the maximum amount of spectrum that could be released, and our analysis in chapter III shows that at least one of the possible reallocations in Los Angeles would produce this much potential cellular spectrum throughout most of the MSA. But in other markets, a reallocation might produce a maximum of only 12 or 6 MHz or could yield different amounts of spectrum over different parts of the MSA.

To determine whether a reallocation would improve social welfare if lesser amounts of spectrum would be released, we estimated the value of 12 and 6 MHz of spectrum in providing cellular service. The results are shown in table 12. It presents the social and market value (present discounted value 1992-2000) of 6, 12, and 18 megahertz of spectrum in Los Angles under two alternative sets of assumptions.

First, we assumed that the newly available spectrum is divided equally between two existing cellular systems and that the additional spectrum does not cause any reduction in prices. This case is presented largely to provide a point of comparison, since we do not consider it a likely or desirable policy alternative. We found that the social value of the first 6 megahertz of new spectrum allocated to cellular would be about $82 million.[113] We found the social value of both 12 and 18 megahertz to be $118 million. In other words, the marginal social value of a third 6 megahertz channel allocated to existing cellular operators is zero. The reason for this is that existing operators will have invested in so many cell sites prior to the introduction of digital technology that they would have vacant channels through the year 2000 if allocated 12

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[113] This is greater than the $30 million estimated by Dale Hatfield and Gene Ax, "The Opportunity Costs of Spectrum Allocated to High Definition Television," paper presented at the Sixteenth Annual Telecommunications Policy Research Conference, Airlie House, Airlie Virginia, October 30, 1988, p. 8. One source of this difference is that our analysis accounted for the benefits of spectrum over the period 1992-2000, while their analysis was for a single point in time. They calculated the benefit of an additional 6 megahertz by comparing the investment cost, with and without the additional spectrum, of building from scratch an analog cellular system to meet the projected demand for the PacTel system in Los Angeles in 1989. In contrast we assumed that prior investments are sunk costs and calculated the benefits of additional spectrum on a forward-going basis, taking into account digital technology and the growth in population.

Table 12

SOCIAL AND MARKET VALUE OF DIFFERENT AMOUNTS OF SPECTRUM IN PROVIDING CELLULAR SERVICE IN LOS ANGELES

Present Discounted Value in 1991 of Annual Values 1992-2000

SPECTRUM DIVIDED BETWEEN 2 EXISTING SYSTEMS, NO PRICE REDUCTION

Spectrum (MHz)	Total Social Value ($ millions)	Change in Social Value ($ millions)	Total Market Value ($ millions)	Change in Market Value ($ millions)
6	82		53	
12	118	36	76	23
18	118	0	76	0

SPECTRUM ASSIGNED TO A THIRD SYSTEM, 25% PRICE REDUCTION

Spectrum (MHz)	Total Social Value ($ millions)	Change in Social Value ($ millions)	Total Market Value ($ millions)	Change in Market Value ($ millions)
6	799		138	
12	893	94	224	86
18	922	29	253	29

megahertz of new spectrum. Thus, the additional 6 megahertz would be of no social or private benefit in providing cellular service.

Second, we assumed that the spectrum is assigned to a third system, whose entry leads to a 25% price reduction. We estimated that 6 megahertz of spectrum assigned to a third cellular system would have a social value of about $799 million. This far exceeds the $139 million social loss from taking a UHF TV station off the air. Thus a reallocation would be socially beneficial even if the new system could operate on only 6 megahertz. Moreover, it would be privately advantageous to make such a reallocation since the market value (considering only the years 1992-2000) of the 6 megahertz in creating a third cellular system in Los Angeles would be about $138 million, which far exceeds the cost of acquiring a UHF TV station.

As expected, we found diminishing marginal benefits from assigning additional spectrum in this case as well. The marginal social benefit of an additional 6 megahertz of spectrum assigned to a third cellular system would be $94 million, and that of another 6 megahertz channel only $29 million. This is far less than the benefit of the first 6 megahertz because we assumed that additional spectrum would reduce costs but not lead to any further price reductions. Of course, the benefit from additional spectrum would be greater when one takes into account demand beyond the year 2000.

B. VALUE OF TV CHANNELS WHEN CELLULAR SPECTRUM OCCUPIED VARIES ACROSS CELL SITES AND EXTENDS BEYOND LOS ANGELES MARKET

The preceding analysis can be refined further to account for the possibility that the cellular spectrum occupied by a UHF television channel may vary within the Los Angeles market and extend beyond that market. As is apparent from the analysis in chapter III, deleting a Los Angeles UHF television station can release spectrum throughout an area containing more cell sites than in the Los Angeles MSA alone. The amount of spectrum released for cellular also tends not to be uniform across existing cell sites, as is shown in the maps in figures 3 and 4 and appendix E.

As we argued in chapter III, each cell site in an optimized pure analog system serves approximately the same amount of cellular traffic, and assuming that demand grows proportionally to current demand, each current cell site also represents approximately an equal unit of future demand. Thus we can estimate the present discounted value of cellular spectrum on a per-cell-site basis by dividing our value estimates for the entire Los Angeles MSA by the number of existing cell sites in that area.

To do this, we note that at the time our cellular data base was constructed, PacTel Cellular had 100 cell sites within the Los Angeles MSA. In the previous section we estimated the social value of 6 MHz, 12 MHz, and 18 MHz of cellular spectrum for a third cellular system in Los Angeles to be $799 million, $893 million, and $922 million respectively. Dividing these by 100 gives a per-cell-site value for the PacTel cells in our data base of $7.99 million, $8.93 million, and $9.22 million for 6 MHz, 12 MHz, and 18 MHz respectively.

By combining these estimates with information about spectrum availability at each cell site in our data base we were able to refine our estimates of the value of cellular spectrum occupied by a UHF television station. Figure 6 in chapter III shows the potential cellular spectrum available at the 138 wireline cell sites in our data base within 104.5 miles of Los Angeles after the deletion of individual UHF television stations. For example, assuming current and future uses are protected (scenario 1), deleting the television assignment on channel 18 would make available 6 MHz at 39 cell sites, 12 MHz at 97 sites, and 18 MHz at 2 sites. Multiplying each of these by the corresponding per-cell-site value results in an estimated social value of $1.196 billion for the spectrum released by deleting channel 18. This is shown in figure 11 along with the estimated social value of potential cellular spectrum that would be released by deleting any of the other UHF television assignments within 40 miles of Los Angeles. Subtracting from these estimates the $139 million social cost of deleting a UHF television channel provides an estimate of the net social gain from a reallocation of each of the channels. Protecting both current and future uses, the greatest net social gain -- $1.057 billion -- would be achieved by reallocating channel 18.

As can be seen from figure 11, the value of spectrum made available for cellular would be somewhat greater if only current uses are protected (scenario 2) than if both current and future uses are protected (scenario 1). For example, if only current uses were protected, the social value of the potential cellular spectrum on channel 18 would be $1.25 billion. Subtracting the social cost of removing a UHF television channel provides an estimate of $1.111 billion as the net social gain from a voluntary reallocation of channel 18 to cellular use while providing interference protection only for current uses.

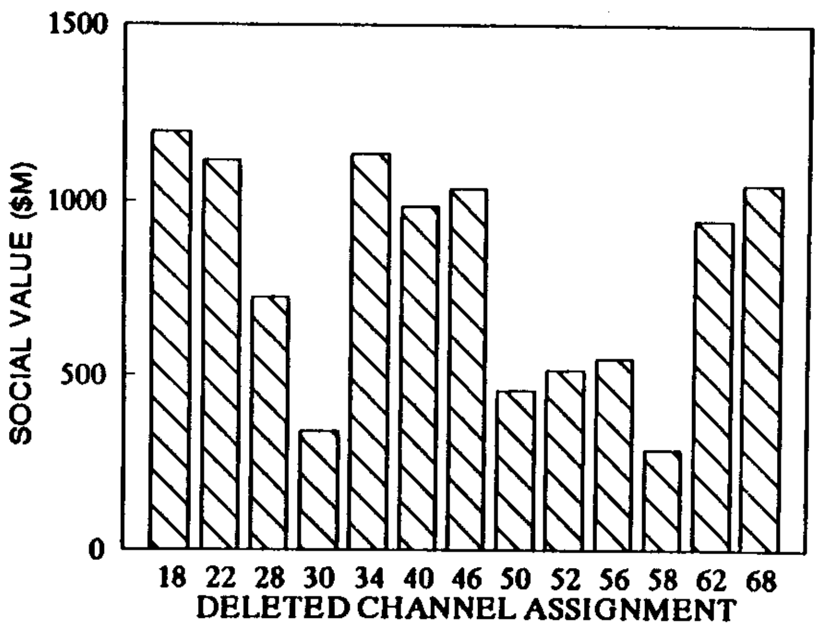
It should be noted that this method of calculating the social value of a cellular system does not account for the importance of contiguous coverage throughout an area users are likely to travel. If there are a significant number of holes in service coverage within the service area, adding up individual cell site values would overstate the total value of a cellular system. Empirically, this does not appear to be serious problem for Los Angeles. Under both scenarios, deleting channel 18, or any of several other channels, would provide at least 6 MHz at a majority of cell sites within a 104.5 mile radius of Los Angeles, and contiguous coverage throughout most

FIGURE 11

SOCIAL VALUE OF CELLULAR SPECTRUM RELEASED BY THE DELETION OF UHF TELEVISION ASSIGNMENTS WITHIN 40 MILES OF LOS ANGELES

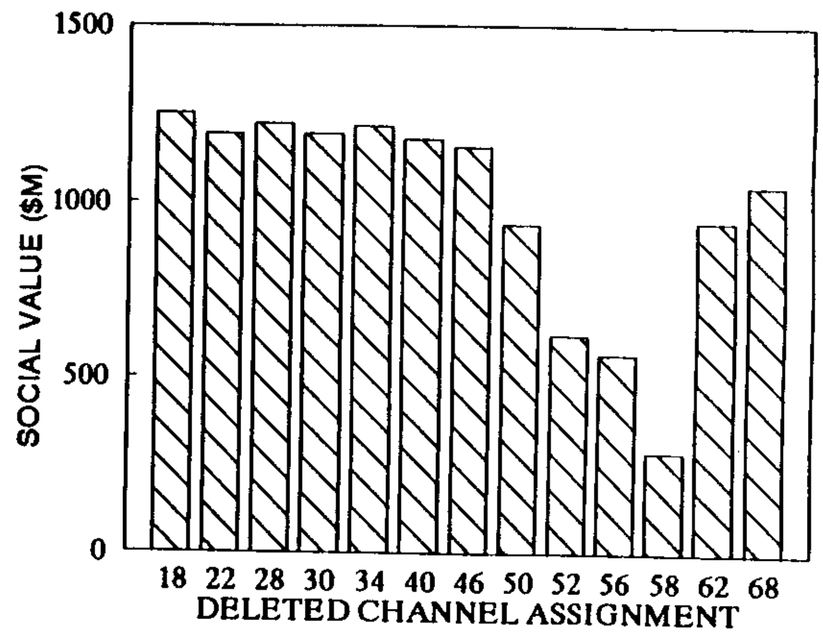
SCENARIO 1
(Existing and Proposed Uses Protected)

DELETED CHANNEL	18	22	28	30	34	40	46	50	52	56	58	62	68
SOCIAL VALUE ($M)	1196	1116	722	338	1134	984	1033	456	512	548	288	942	1048



SCENARIO 2
(Exising Uses Protected)

DELETED CHANNEL	18	22	28	30	34	40	46	50	52	56	58	62	68
SOCIAL VALUE ($M)	1250	1191	1220	1194	1213	1178	1155	936	622	566	288	942	1048



NOTES:

1. Each bar represents the column of data directly above it.
2. Scenario 1 assumes protection of existing full power television assignment and allotments, existing low power television assignments, current and proposed land mobile sharing channels, and hypothetical HDTV allotments,
3. Scenario 2 assumes protection of existing full power television assignments and allotments, existing low power television assignments and current land mobile sharing channels.

or all of the Los Angeles MSA. This can be seen from the maps in appendix E.

C. COST OF DELAY

Our analysis suggests that social welfare could be increased by creating a third cellular system with spectrum currently used to provide UHF television service. But, what if there are other uses more valuable than cellular or, more likely, other sources of spectrum with a lower opportunity cost than UHF TV? Should the reallocation of spectrum from UHF television to cellular be delayed while an attempt is made to determine an optimum spectrum reallocation across all uses and bands? We think not. A lengthy delay for a broader analysis could be very costly.

To gain some insight into the cost of such delay we examined whether social welfare would be increased by delaying entry of a third cellular system three years if spectrum with no opportunity cost would then be available. The benefit of such a delay would be the social value of a UHF TV station, since the station would not be taken off the air. The cost would be the loss in consumer plus producer surplus from higher cellular prices, lower cellular output, and higher cellular costs for the three years entry is delayed. Our analysis involved comparing two specific options.

Under option 1 we assumed that a third cellular system would begin operation in 1992 using spectrum made available by taking a UHF TV station off the air and that such entry would result in a 25% price reduction (as described in case 4 in chapter V). To allow for the constraints imposed by ATV we assumed that only 12 megahertz of spectrum would be made available. We also assumed that under option 1 the UHF TV station reallocated to cellular would go off the air forever.[114]

To make the most favorable case for delay, under option 2 we assumed that 18 megahertz of spectrum with no opportunity cost would become available in 1995 and would be used to create a third cellular system. Assuming such "free" spectrum makes it easy to determine the opportunity cost of spectrum for which the two options would be of equal value. As with option 1, we assumed that entry would reduce price by 25%, but in this case the reduction would not begin until 1995.

For both options we extended our analysis beyond the year 2000 by assuming a terminal value for cellular and UHF TV in the year 2001 equal to ten times producer and consumer

[114] Allowing for the possibility that the cellular system that entered in 1992 might switch to some other frequency after the free spectrum became available in 1995 and that the UHF TV station might go back on the air could only make option 1 more attractive.

surplus in the year 2000. We did this because terminating the analysis in the year 2000 might disadvantage option 2 (delaying to 1995) by providing too short a period over which to recover the fixed costs of investment in cellular equipment and not accounting for the value of TV service for the years 2001 and beyond.

As shown in table 13, the social value of option 2 (delay) was about $6.9 million more than option 1. This result holds, however, only for the assumption that the spectrum used under option 2 is "free," i.e., has no opportunity cost. In reality, however, there will always be some cost -- and it will likely be more than $6.9 million. Moreover, an immediate voluntary reallocation of UHF spectrum would still be better than waiting, if the wait for free spectrum is over three years.

D. EXTENSION TO OTHER MARKETS

We examined only the Los Angeles market. While ideally the analysis should be performed for all markets, one can gain insight into the likely outcome of such an exercise by examining the sensitivity of our results for Los Angeles to changes in factors that differ across markets. Three such factors discussed in this section are the number of over-the-air stations, percentage of homes passed by cable, and the price of cellular service. The first two affect the social cost of taking a television station off the air, while the third influences the social benefit of creating a third cellular system.

1. Number of Television Stations and Percent Homes Passed by Cable

Table 14 shows how the marginal annual value per household of an independent UHF television station varies with the total number of stations that can be received.[115] As shown in table 14, we found that for markets like Los Angeles with 16 over-the-air stations, the average annual loss from taking an independent station off the air was $20.49 for households not passed by cable, and $5.98 for those passed by cable but not subscribing. In markets with only 7 stations the loss would be over three and one-half times as great -- $75.39 for households not passed by cable and $21.59 for households passed but not subscribing.

The social value of a television station also includes producer surplus (before-tax profits). We would expect station profits, which reflect the value advertisers place on reaching potential

[115] Our methodology is described in section IV and Appendix B. For households passed by cable but not subscribing, the average value of an over-the-air UHF TV signal depends on the percentage of homes passed that subscribe. For a given distribution of willingness to pay for a signal, the greater the percentage subscribing the lower the average valuation of remaining non-subscribers. We assumed that 57% of homes passed subscribe. This is the level we predicted for Los Angeles in 1992. It is below the national average in 1990 of 72%, but above the 45% in Los Angeles in 1988.

Table 13

CHANGE IN SOCIAL WELFARE FROM DELAYING ENTRY OF A THIRD CELLULAR SYSTEM 3 YEARS AT WHICH TIME SPECTRUM WITH NO OPPORTUNITY COST BECOMES AVAILABLE
($ millions)

CELLULAR

Producer Surplus (before tax profit)

	Incumbents (System A)	Incumbents (System B)	Entrant (System C)	Total
Option 1 -- Enter 1992				
(25% price reduction 1992-)				
Spectrum MHz	25	25	12	62
PV producer surp. 1992-2000	1179.3	1179.3	447.1	2805.7
PV terminal value 2001	1577.4	1577.4	968.6	4123.4
PV producer surplus 1992-	2756.7	2756.7	1415.7	6929.1
Option 2 -- Enter 1995				
(25% price reduction 1995-)				
Spectrum MHz	25	25	18	
PV producer surp. 1992-2000	1653.2	1653.2	266.9	3573.3
PV terminal value 2001	1684.5	1684.5	730.0	4099.0
PV producer surplus 1992-	3337.7	3337.7	996.9	7672.3
Gain in cellular producer surplus from delaying entry 3 yrs. (PV)				743.3

Consumer Surplus

Loss in cellular consumer surplus from delaying entry 3 years (PV of loss from delaying 25% price reduction from 1992 to 1995)	-957.6

Consumer Surplus Plus Producer Surplus

Loss in cellular consumer plus producer surplus from delay (PV)	-214.4

UHF TV

Consumer Plus Producer Surplus

Gain in UHF TV consumer plus producer surplus from 3 year delay	
PV consumer + producer surplus 1992-2000	139.2
PV terminal value 2001	82.1
PV consumer + producer surplus 1992-	221.3

CELLULAR PLUS UHF TV

Change in total consumer plus producer surplus from 3 yr. delay (PV)	6.9

Table 14

ESTIMATED MARGINAL ANNUAL VALUE PER HOUSEHOLD OF AN INDEPENDENT TV STATION*

Total Number of TV Stations**	Value Per TV Household Not Passed By Cable ($)	Value Per TV Household Passed By Cable But Not Subscribing*** ($)
7	75.39	21.59
8	58.21	16.73
9	47.38	13.66
10	39.94	11.54
11	34.51	9.99
12	30.37	8.81
13	27.11	7.88
14	24.48	7.12
15	22.31	6.50
16	20.49	5.98

NOTES:

* Based on model and parameters estimated by Noll, Peck, and McGowan (1973). See Appendix B.

** Assumes 4 affiliated stations and the remainder independent.

*** Assumes 57% of homes passed subscribe to cable. See Appendix B for discussion of how we modified the Noll, Peck, and McGowan model to estimate the value per household passed by cable but not subscribing.

consumers, to depend on the same factors that determine consumer surplus. Station profits are likely to be greater if there are more television households in the market, fewer total stations, and fewer homes passed by cable (within the signal area of the station). We have not, however, developed a full model to account for these factors, and thus -- for present purposes -- we assumed that producer surplus remains constant. Given that for the base case producer surplus accounted for only 23% of total social value of a Los Angeles television station, we would not expect this assumption to result in a large percentage error in our estimates of total social value.[116]

Table 15 gives estimates of the marginal social value of a UHF TV station in Los Angeles under alternative counterfactual assumptions about the percentage of homes passed by cable and the number of over-the-air TV stations. The results were calculated using the estimates from table 14 and the same spreadsheet used to produce table 3 in chapter IV.[117] According to this analysis if there were only 7 television stations in the Los Angeles market and 90 percent of homes were passed by cable, the social loss from taking one UHF station off the air would be about $457.4 million -- well below our estimate of $893 million from creating a 12 megahertz third cellular system in Los Angeles (see table 16). Indeed, with 7 television stations the percentage of homes passed by cable could fall as low as 70 percent and the social cost of taking a station off the air would still be less than the social benefit of a new cellular system.

Table 15 also shows combinations of total number of television stations and the percentage of homes passed by cable that provide approximately equivalent marginal social value. For example, the following combinations of stations and percentages of homes passed all result in a station having a marginal social value of approximately $360 million: 7 stations and 95% homes passed, 8 stations and 90%, 9 stations and 85%, 10 stations and 80%, and 12 stations and 70%.

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116 We assumed a trading price of $35 million for the least valuable UHF TV station covering downtown Los Angeles. To assess the range of producer surplus across markets we examined the trading prices of all commercial UHF television stations sold in 1987. The average trading price for all 19 sales was $9 million. The highest sale price was $72 million for WPHL in Philadelphia, the 4th largest ADI market, and the lowest price was $1.7 million for KLXV in San Jose, the 5th largest ADI market. Broadcasting (February, 1988).

117 In generating table 3, however, as the percentage of homes passed subscribing rose over time, we made the additional refinement of recalculating the value per TV household passed by cable but not subscribing. To reduce computation, table 15 was calculated for all years using the value per household passed but not subscribing shown in table 14, which was based on 57% of homes passed subscribing. This simplification tends to slightly overstate the social value of a UHF TV station.

Table 15

MARGINAL SOCIAL VALUE OF A UHF TV STATION IN LOS ANGELES UNDER ALTERNATIVE COUNTERFACTUAL ASSUMPTIONS ABOUT PERCENT OF HOMES PASSED BY CABLE AND NUMBER OF OVER-THE-AIR TV STATIONS

Present Value of Consumer Plus Producer Surplus 1992-2000
($ millions)

Total Number of TV Stations*	Percent of Homes Passed by Cable (%)				
	70	80	85	90	95
7	853.2	655.3	556.3	457.4	358.4
8	666.4	513.7	437.3	360.9	284.5
9	548.6	424.3	362.2	300.0	237.9
10	467.6	362.8	310.5	258.1	205.7
11	408.4	317.9	272.7	227.5	182.2
12	363.4	283.7	243.9	204.1	164.3

NOTES:

* Assumes 4 affiliated stations and the remainder independent.

Table 16

SOCIAL VALUE OF SPECTRUM IN PROVIDING CELLULAR SERVICE IN LOS ANGELES UNDER ALTERNATIVE BASE-CASE PRICE FORECASTS

Present Value of Producer Plus Consumer Surplus 1992-2000
($ millions)

Spectrum (MHz)	Price Forecast For L.A. Market (High Prices)	Price Forecast For Typical Market (Lower Prices)
6	799	322
12	893	416
18	922	445

NOTES:

(1) Estimates assumed spectrum is assigned to a third system and that entry results in a 25% price reduction compared to the base-case forecast.

(2) Estimates were based on the following alternative forecasts of cellular prices for the base case:

Revenue/subscriber/month ($)

	1992	1993	1994	1995	1996	1997	1998	1999	2000
L.A. Market	120	115	110	105	100	95	90	85	80
Typical Market	91	89	86	83	81	78	76	74	72

2. Prices for Cellular Service

Prices for cellular service differ widely across markets. Assuming that marginal cost does not differ widely across markets, the benefit of the entry of third cellular system is likely to be greater in markets with high prices than in ones with low prices. Since Los Angeles is a relatively high-priced market, we would expect that the benefit of shifting spectrum from UHF TV to cellular would be less in a more typical cellular market.[118]

To assess the effect of lower initial cellular prices on the benefit of a third cellular system we recalculated our estimates for Los Angeles using projected cellular prices for a typical cellular company.[119] For this case, we estimated that the social value of a third cellular system would be $445 million, which is considerably less than our $922 million estimate based on our projection of prices in Los Angeles (see table 16). For both cases we assumed that taking a UHF TV station off the air would release 18 megahertz of spectrum for cellular use, and that entry of a third cellular system would cause prices to fall 25%. Repeating the same analysis under the assumption that a UHF TV station would release 12 megahertz of cellular spectrum reduced our estimate of the social value of a third cellular system to $416 million for a typical cellular market. Assuming it releases only 6 megahertz further reduced the estimate to $322 million.

In our model, for a given percentage price reduction the welfare gain is smaller when the initial price is lower for two reasons. First, a given percentage reduction implies a smaller absolute price reduction and a smaller absolute output expansion. Second, with a smaller gap between price and marginal cost, the social benefit of a given output expansion is less.

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118 We calculated the price of cellular service in 20 cities for a hypothetical customer using a total of 300 minutes per month with 80% during the peak period and 20% off-peak. For wireline carriers the highest monthly price was $197 in New York and the lowest was $89 in Sacramento. The price in Los Angeles was $169 and the median was $129. The data were from National Cellular Reseller Association, Petition to Expand Rulemaking Proceeding (RM 6539), December 6, 1988.

119 We used projections by Leibowitz et al, The Cellular Communications Industry, Donaldson, Lufkin, and Jenrette (Spring 1990) p. 16. They forecast that the revenue per subscriber month will be $91 in 1992 and will fall gradually to $72 in 2000, while we assumed that for Los Angeles it would be $120 in 1992 and fall gradually to $80 in 2000. See notes in table 18.

VII. RECOMMENDATIONS AND CONCLUSIONS

This paper provides strong evidence that social welfare could be increased by creating a third cellular system in Los Angeles through the voluntary reallocation of spectrum occupied by a UHF television channel. Even assuming that ATV channels would be fully protected, we estimated that converting one of the currently occupied UHF television channels for the years 1992-2000 would provide a net social gain of over one billion dollars.

Such a voluntary reallocation is likely to be socially beneficial in other markets as well. Assuming that both television and cellular social values are approximately proportional to population, we can extrapolate our analysis of Los Angeles to other markets. For example, our analysis suggests that a reallocation would be justified in a high-price cellular market as long as there are at least seven television stations and 70 percent of the homes are passed by cable.[120] For a cellular market with lower prices the social benefit of additional cellular competition would be less, so there would have to be more television stations or a higher percentage of homes passed by cable to justify a reallocation. Our analysis suggests that any of the following combinations would be sufficient in a typical-price cellular market: seven stations and 95 percent of homes passed, eight stations and 90 percent, 9 stations and 85 percent, 10 stations and 80 percent, or 12 stations and 70 percent.[121]

Despite the large potential net benefits from creating an additional cellular system in this way, the substantial social cost of losing a television channel suggests that an effort should be made to consider other, possibly lower cost, sources of spectrum. For example, it is possible that some amount of cellular use of this band may be possible on a shared basis after the implementation of ATV, especially if any remaining spectrum on the proposed land mobile sharing channels is included. Another alternative would be spectrum between 1850 and 2200 MHz, some of which the Commission has proposed to allocate to PCS.[122] A more comprehensive study of such other options would seem to be appropriate before permitting reallocation of occupied UHF television channels.

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120 See tables 15 and 16. This assumes that the reallocation would provide 12 megahertz of spectrum for a third cellular system, which was the case for three stations in Los Angeles while giving full protection to ATV.

121 We estimated the cellular benefit of 12 MHz in a typical-price market as $416 million. This exceeds the estimated cost of about $360 million for removing a television station in a market with the various combinations of stations and homes passed. See tables 15 and 16

122 Notice of Proposed Rule Making and Tentative Decision, FCC 92-333, GEN Docket No. 90-314, ET Docket No. 92-100, July 16, 1992.

On the other hand, the time required to free other spectrum for cellular use once a decision is made to do so must also be considered. As discussed in section VI, there is a high opportunity cost in delaying the benefits of additional cellular competition. We premise the following policy proposal on the assumption that a reasonable search has been conducted and it has been concluded that there are no such relatively low-cost sources of spectrum likely to be available in the near future.

A. A PROPOSAL FOR VOLUNTARY REALLOCATION OF SPECTRUM FROM UHF TV TO CELLULAR SERVICE

We propose that the Commission authorize the voluntary reallocation of one commercial UHF television channel in each television market to establish a third cellular system -- if and only if the reallocation passes a benefit- cost test. Factors considered in such a test would include: (1) the amount of spectrum made available for cellular; (2) the demand for cellular service in the area where spectrum becomes available; (3) the prices charged by the incumbent cellular operators; (4) the number of television stations in the market; (5) the number of households served by the displaced television station; and (6) the percentage of such households passed by cable.[123] If more than one licensee wishes to convert to cellular and passes the test, the one that would provide the largest net benefit according to the test would be granted voluntary reallocation authority.

All other current and planned uses of the band, including unused NTSC television allotments, land mobile sharing channels, and ATV, would be preserved and protected from interference. To ensure against any possible conflict with ongoing ATV planning, voluntary NTSC channel reallocations would not be permitted until after ATV allotments have been made.[124] Also, reallocation of ATV channels would not be permitted. All ATV allotments would be protected from interference and preserved for future broadcast use.

The specific benefit-cost formula would be based on forecasts of factors such as cellular demand and the number of cellular competitors. Over time these forecasts may need to be revised

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[123] In extending the analysis to other markets it may be necessary to consider factors not taken into account in our analysis of a single market. For example, there may be an advantage to having all channels converted nationwide within some narrow frequency range. This could reduce the cost of manufacturing mobile units that would be able to operate in all areas.

[124] There could be a conflict with ATV on all three of the channels that would be potentially released for cellular use by deleting a NTSC assignment. This is because ATV allotments could be made on the two channels adjacent to a NTSC channel in the same area and on the NTSC channel itself with as little as 100 miles of separation.

as new information becomes available. Thus we propose that the formula be reviewed periodically and whenever any significant unanticipated changes in such factors occur.

Reallocation would, initially, be limited to one channel per market. We do not rule out the possibility that social welfare would be increased by permitting the reallocation of more than one channel in certain markets, but such channels are less likely to pass a benefit-cost test than the first channel.[125] As additional television channels in a market are removed, the loss to viewers per channel increases while the marginal benefit from additional cellular competition diminishes.[126] Reallocation could later be permitted for additional channels if further analysis supports it.

Reallocation would also be limited to markets with four unduplicated stations affiliated with the four largest commercial networks. Viewers place the highest value on such stations, and our analysis is premised on the assumption that such stations would be available.

To maximize social value, we would require that the reallocated spectrum be used for services competitive with cellular rather than assigned to existing cellular systems. This would include services which are close substitutes for conventional cellular mobile telephone service, although not identical. To meet this requirement such a service would have to be interconnected to the public switched telephone network on terms at least as favorable as existing cellular service. Also, the existing cellular licensees in a market should be barred from owning or subsequently acquiring any interest in any reallocation application or any cellular system operating on reallocated spectrum within their own cellular markets.

Subject to protecting other uses of UHF spectrum, cellular service would be permitted on the reallocated NTSC channel plus the two adjacent channels. A single reallocation could thus yield a maximum of 18 MHz of cellular spectrum. We would limit the authorized cellular service area to within a 100 mile radius of the center of the largest MSA in the television market where the reallocated channel is located.[127] To provide reciprocal protection to the new

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125 If this approach were adopted and more than one qualified application is filed, the Commission would need a selection method. One possibility would be to select the application yielding the greatest cellular value, as calculated along the lines discussed in section VI in the subsection "Value of TV Channels when Cellular Spectrum Occupied Varies across Sites and Extends beyond the Los Angeles Market.

126 In a Cournot model of identical firms, "The effect of additional rivals on quantity and price is initially very strong but tapers off as the number of firms increases." Carlton and Perloff, p. 269.

127 Television markets could be defined according to Arbitron's "area of dominant influence" (ADI). Because different portions of the 100 mile circle are likely to be excluded on each of the channels, the result will be three different and probably overlapping service areas. The union of these three areas would define the overall system service area.

cellular service, no future changes or additions to other spectrum uses would be authorized on these or adjacent channels that would reduce the size of a previously authorized cellular service area. However, since all existing and currently proposed users would be protected, the impact of protecting cellular use would be minimal.

B. APPLYING VOLUNTARY REALLOCATIONS MORE BROADLY

A policy such as the one described above allowing limited voluntary reallocations of UHF television channels may be the most practical and cost effective way to obtain spectrum for a third cellular system. By contrast, involuntary reallocation would take much longer to complete, as the administrative reallocation procedure is carried out and time is provided for the amortization of investments in the band. As shown in chapter VI, much of the value of a third cellular system would be lost by a delay of only a few years.

Initiating a limited voluntary reallocation policy in the UHF television band could facilitate the development of high-value services other than conventional cellular, such as personal communications services, local area networks, cordless telephones, wireless PBXs, and digital audio broadcasting. Recent trends suggest that the continued development of cable, optical fiber to the home, and direct broadcast satellites, may gradually diminish the value of traditional broadcasting in the delivery of television services to the home.[128] At the same time, telephone and other forms of personal communications are migrating increasingly to radio to meet the growing demand for mobility.[129] A properly supervised voluntary reallocation policy in this spectrum would allow change to occur gradually in response to market forces, without major dislocations to either consumers or producers. This approach would provide certain incumbent broadcasters the opportunity to shift their spectrum to a higher-valued use, increasing the market value of their licenses.[130] Moreover, since it would be voluntary, only those who expect to

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[128] See, Florence Setzer and Jonathan Levy, Broadcast Television in a Multichannel Marketplace. U.S. Federal Communication, Office of Plans and Policy, Working Paper No. 26 (June 1991)

[129] Nicholas Negroponte has argued that "over the next 20 years ... the channels for distributing different types of information, as we know them today, will trade places. Most information we receive through the ether today -- will come through the ground by cable tomorrow. Conversely, most of what we now receive through the ground -- such as telephone service -- will come through the airwaves." Nicholas Negroponte, "Products and Services for Computer Networks," Scientific American, (September 1991, Special Issue), 108.

[130] The distribution of the benefits to incumbent UHF TV licensees would depend, in part, on the method the FCC uses to assign the right to reallocate spectrum from UHF TV to cellular service. If, for example, the Commission were to use a simple publicly available benefit-cost formula which unambiguously gave one UHF TV licensee the highest score, only that licensee would experience an increase in market value. Alternatively, if the Commission used a lottery to select among all UHF licenses in a market, prior to the lottery, the market value of each station would increase by approximately $(C - T)/n$, where C is the present value of profits if the spectrum is used for cellular service, T is the

benefit would participate. In addition, by providing a private alternative to lengthy public spectrum allocation procedures, voluntary reallocation would facilitate technological innovation and competitive entry in future telecommunications markets.

Voluntary reallocation may be usefully applied to spectrum other than UHF television. This approach was raised in the Commission's personal communications services (PCS) Notice of Inquiry and recently adopted in limited form as a means of reallocating occupied spectrum for emerging technologies.[131] Under this plan, licenses for new services can be issued immediately without waiting for the band to be cleared of its existing occupants. The new licensees can implement their service on the remaining unoccupied spectrum in the band and can negotiate with the existing licensees for access to additional spectrum as it is needed.[132] Since there is little reason to expect a significant divergence between private and social costs for these services, we believe that there is no need for individual benefit-cost tests for such voluntary reallocations. Once the FCC has issued licenses for the new service, occupied spectrum can be reallocated as quickly as the market dictates.

Moreover, by making the new licensees bear the cost of displacing existing systems, they will have incentives to seek out less costly alternatives such as the use of more efficient radio technology or sophisticated sharing techniques. The amount of occupied spectrum that is reallocated can adjust gradually to the needs of the new service. Since new users would pay incumbents to move, they would be unlikely to require the displacement of systems until they are ready to put the reallocated spectrum to use. Only as much occupied spectrum would be reallocated as could be justified by a realistic assessment of the market.

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present value of profits if the spectrum is used for TV broadcasting, and n is the number of stations in the lottery. After the lottery, the market value of the winning licensee would increase to C, while the market values of the other stations would return to approximately their original levels. The market values of these remaining stations would be slightly greater than before to the extent that advertising rates would be greater with one fewer station in the market.

131 See footnote 3, <u>supra</u>.

132 After a transition period, relocation can be required, but compensation would still have to be paid.

APPENDIX A:
FEASIBILITY OF CELLULAR USE AT MINIMUM SPACING

In calculating potential cellular spectrum availability we have determined that cell sites could be located as close as 95.5 miles from co- channel full power television stations and 68 miles from adjacent channel TV stations without causing interference to television service. However, there is also a potential for interference from television to cellular at these distances. The principal effect of such interference would be a reduction in the effective communication range between the base station and mobiles within a cell. This communications range determines maximum cell size. If cells must be smaller because of interference than is justified by traffic considerations, system costs will be increased and the value of this spectrum to cellular reduced.

A. CO-CHANNEL INTERFERENCE

Worst case co-channel interference conditions are depicted in figure A-1, which shows a cell site located at the 95.5 mile minimum separation from a co-channel TV station on channel N. The cell site in the drawing is partitioned into three sectors and the base station and mobiles operating in sector A are transmitting and receiving on channel N and therefore co-channel with the TV station. Transmitters in the other two sectors might be using the adjacent channels N-1 and N+1, if available, which would correspond to a system designed to operate over three contiguous TV channels.[133] With this site design, mobiles transmitting on channel N would always remain beyond the required 95.5 mile separation.

The base station in the drawing radiates 100 watts (ERP) of power from an antenna height of 100 feet above average terrain in a direction away from the TV station. The mobiles in sector A radiate 7 watts omnidirectionally from a height of 6 feet above average terrain.[134] To protect the TV station, the base station in the drawing also radiates no more than 7 watts in the direction of the TV station (the 95.5 mile minimum separation is based on 7 watts at 100 feet).

Base and mobile receivers operating in sector A in the drawing would be subject to co-channel interference from the TV station. The magnitude of this interference would depend on the ratio of the desired and undesired signal strengths at the receivers and the interference rejection characteristics of the cellular system.

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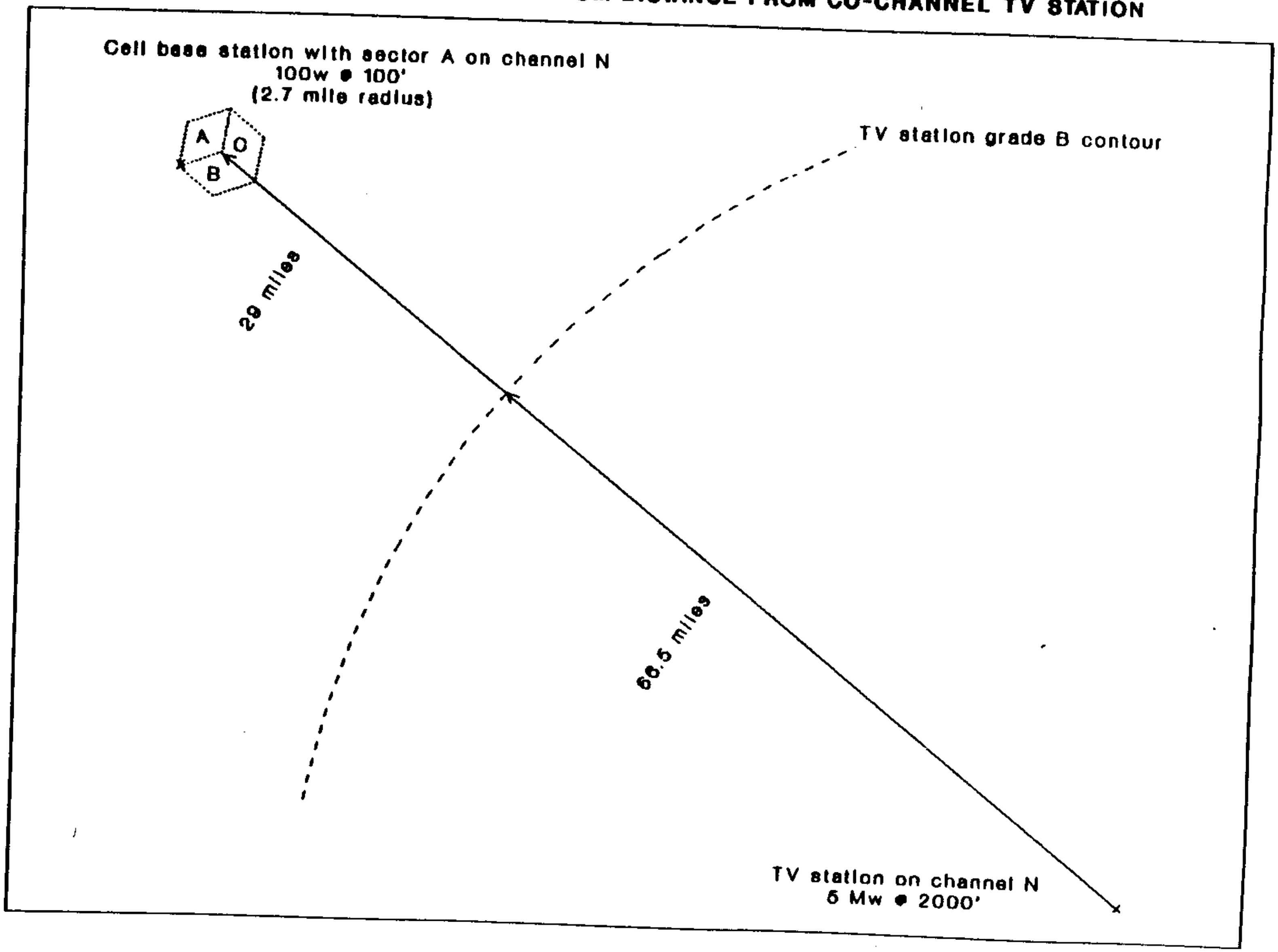
[133] If only channel N were available, sectors B and C in the drawing would be inoperative.

[134] In the body of the paper we used a mobile antenna of 100 feet to be conservative in our calculation of potential interference to television. Here we use a lower mobile antenna height to provide a more accurate estimation of cellular service capability.

Figure A-1
CELLULAR OPERATION AT MINIMUM DISTANCE FROM CO-CHANNEL TV STATION



1. Interference to the Base Station Receiver

At the base station antenna, the interfering TV signal would have an F(50,10)[135] field strength of 63 dBu, plus 2 dB to correct for the height of the base station antenna.[136] Because the TV and cellular signals are oppositely polarized, the base station antenna will reduce the effective strength of the TV signal 10 dB relative to the desired signal.[137] Also, the base station antenna's front-to-back ratio will further reduce the TV signal's relative strength by 25 dB.[138] The effective strength of the TV signal at the base station would therefore be 63 + 2 - 25 -10 = 30 dBu at the base station antenna.

If the base station in figure A-1 requires the same 17 dB signal-to-interference ratio as current cellular systems, the strength of the mobile signal at the base station would have to be at least 30 + 17 = 47 dBu to overcome the interference. A 7 watt mobile at 6 feet antenna height would provide a 47 dBu signal at the base station from a distance of approximately 3 miles.[139] A cell radius of three miles would be appropriate in congested areas but might be too small in a rural environment. However, cell radius could be increased to approximately 5 miles by avoiding operation on frequencies near the TV station's visual and aural carriers.[140]

2. Interference to Mobile Receivers.

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135 The nomenclature F(50,10) and F(50,50) refers to the propagation curves used to make the distance/field strength calculations. In interference calculations it is customary to use the F(50,10) curves when calculating the strength of undesired signals and the F(50,50) for the desired signal. The numbers in these designators represent the probability that the actual signal will exceed the value predicted by the curves at different locations and times: F(50,50) values will be exceeded at 50 percent of locations at this distance 50 percent of the time and F(50,10) values at 50 percent of locations 10 percent of the time. Thus at a given distance the F(50,10) curves predict a higher field strength than do the F(50,50) curves.

136 The propagation curves assume a receiving antenna height of 10 meters (32.8 feet) above average terrain while we have assumed a base station antenna height of 100 feet. At a distance of 95.5 miles, increasing antenna height from 32.8 to 100 feet increases the predicted F(50,10) field strength values by approximately 2 dB.

137 In the Further Sharing Notice, the Commission concluded that 10 dB cross polarization discrimination between TV and land mobile signals can be expected on average.

138 According to cellular industry sources, a 120 degree sector antenna provides from 20 to 25 dB of "front-to-back" discrimination. The higher ratio antenna would be likely to be used in a situation like this where interference reduction is critical.

139 Extrapolated from Figure 3 of Roger Carey, Technical Factors Affecting the Assignment of Facilities in the Domestic Public Land Mobile Radio Service. FCC Report R-6406 (June 1964). Path reciprocity is assumed.

140 An idealized TV emission envelope is depicted in CFR 73.699, fig. 5. Over most of the TV emission bandwidth, field strength would be 6 dB lower than we used in our calculations. A 6 dB reduction in the TV signal would allow for a cell radius of approximately 5 miles.

Interference to the mobile receiver must also be considered. The worst case would be a mobile located at point X in the drawing, where the mobile is farthest away from the base and closest to the TV station. With a 3 mile cell, the distance from point X to the TV station would be approximately 95.5 + (3 / 2) = 97 miles. At this distance the F(50,10) field strength of the interfering signal would be 62.5 dBu. Reducing this 5 dB to adjust for the lower mobile antenna height[141] and 10 dB due to polarization discrimination by the mobile antenna results in an interfering signal strength of 47.5 dBu at mobile unit. To get the required 17 dB signal-to-interference ratio, the base station would need to produce a 47.5 + 17 = 64.5 dBu signal at the mobile unit. From the propagation curves,[142] a 100 watt transmitter at an antenna height of 100 feet would produce a field strength of only 60 dBu at 3 miles, insufficient to overcome the interference from the TV station.

The excess interference in this case can be overcome by several means. One way, discussed above, would be to avoid using the TV station's visual and aural carrier frequencies. This would reduce the interference by approximately 6 dB. It would also be possible to increase the strength of the desired signal 4.5 dB by increasing the power radiated into the cell by the base station from 100 watts to 282 watts. Current cellular rules allow base station power up to 500 watts in rural situations. Interference to the TV station would be prevented by the directivity of the base station antenna. With a 25 dB front-to-back ratio, as much as 2000 watts could be radiated into the cell without exceeding the 7 watt limit in the direction of the TV station.

B. ADJACENT CHANNEL INTERFERENCE

In the adjacent channel case, the high degree of selectivity of cellular receivers would effectively eliminate any potential for interference from television stations at the distance separation of 68 miles. A 1986 FCC technical report concludes on the basis of actual lab tests that "the amplitude of the undesired television signal necessary to produce a degradation in the land mobile signal had to be much larger, on the order of 70 to 90 dB greater than the desired land mobile signal."[143] The weakest usable cellular signal in the absence of interference is about 39 dBu. To interfere with this minimal cellular signal would require an adjacent channel TV signal of at least 39 + 70 = 109 dBu field strength. TV F(50,10) signals of this magnitude

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141 By extrapolating the F(50,10) curves it appears that a reduction in antenna height from 32.8 feet to 6 feet would reduce field strength by approximately 5 dB at these separation distances.

142 Carey report, note 139, supra.

143 Daniel J. Stanks, Receiver Susceptibility Measurements Relating to Interference Between UHF Television and Land Mobile Radio Services. Project No. EEB-84-4, FCC/OET TM87-1 (Washington, D.C.: FCC, April 1986).

would exist only within 14 miles of the TV station, much less than the 68 mile separation needed to protect the television service from interference from cellular.

C. CONCLUSION

The analysis in this section suggests that co-channel interference from television to cellular would impose some additional cost or capacity constraints at cell sites close to the minimum distance separation. Sites farther away from co-channel TV stations would be less affected. Where a channel is shown to be available for cellular use throughout most of an area, which is the case of interest in this study, the most restricted cell sites would be those on the fringe of the metropolitan area. The cost of serving some of those outlying areas would be increased because of co-channel interference considerations. However, since there are fewer sites in such areas, overall system costs would be increased only minimally.

APPENDIX B:
CALCULATING THE VALUE OF A TV CHANNEL TO VIEWERS

The analysis in chapter IV relied on estimates by Noll, Peck, and McGowan (N-P-M) to calculate the value of over-the-air television channels to television viewers.[144] This appendix summarizes their model and shows how we extended it to estimate the value of over-the-air television to households passed by cable but not subscribing.

Noll, Peck, and McGowan assumed that the maximum cable subscription fee the Nth potential subscriber is willing to pay is given by

(B-1) $$P = Y*[1-T(x)^{\ln\frac{N}{N_P}}]$$

where P = the maximum annual price at which the Nth subscriber would subscribe to cable, where subscribers are ranked from highest to lowest willingness to pay.

Y = annual household income. For purposes of estimation N-P-M assumed that all households in a city have the same income.

N = actual number of subscribers.

N_p = potential number of subscribers (total number of television households).

$T(x)$ = quality of cable television relative to over-the-air ("free") television.

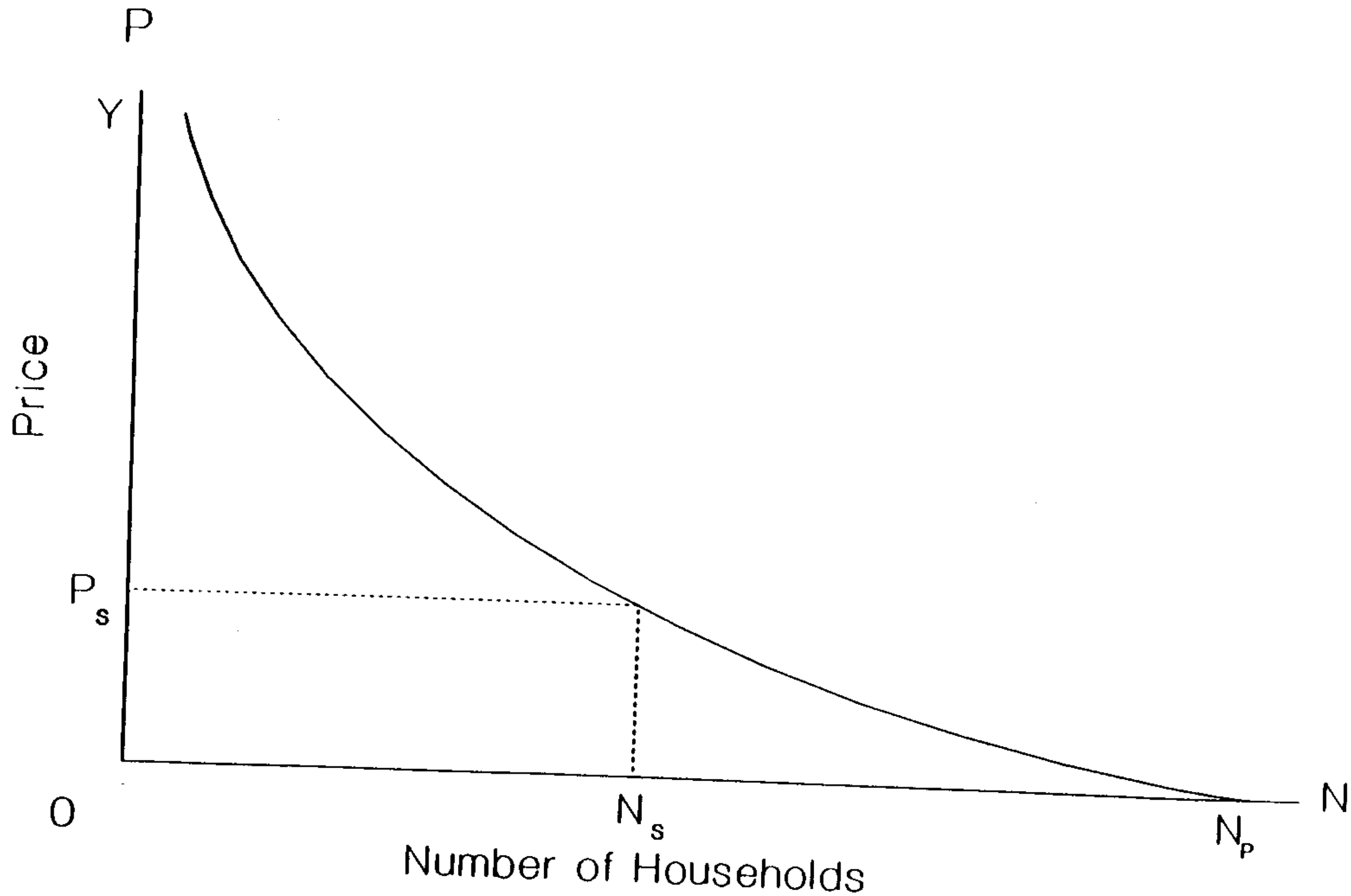
The demand curve for cable TV can be thought of as providing in rank order the maximum subscription fee potential subscribers are willing to pay. Equation (B-1) implies that the valuation of cable ranges from virtually the entire household income (as N approaches 0, P approaches Y) to zero (for $N = N_p$, $P = 0$). This is shown in figure B-1.

N-P-M estimated the quality of cable and over-the-air service as a function of the numbers and types of stations each offers. We will focus on the two types of stations that their

[144] For a detailed explanation of their methodology and results see Noll, Peck, and McGowan, Appendix A, pp. 277-288.

Figure B-1

Demand for Television



empirical analysis found to be most important: network-affiliated and independent. They assumed that

(B-2) $$T(X) = (X_A)^a (X_I)^b$$

where

$X_A = (1 + A^c)/(1 + A^f)$, relative number of network alternatives

$X_I = (1 + I^c)/(1 + I^f)$, relative number of independent stations

A^c = number of primary network alternatives (unduplicated network stations) available on cable.

A^f = number of primary network alternatives available over the air on free television.

I^c = number of independent stations available on cable.

I^f = number of independent stations available on free television.

a = parameter estimated by N-P-M to be .0385 (p. 286).

b = parameter estimated by N-P-M to be .0098 (p. 286).

Increasing the number of stations available on cable or decreasing the number available over the air increases the relative quality of cable, $T(x)$, and hence the maximum amount a potential subscriber would pay for cable, P.[145] The estimated values of a and b indicate that an additional network station is worth considerably more to viewers than an additional independent station. In terms of figure B-1, increasing T shifts out the demand curve except for the end points.

To estimate the value of free television N-P-M assumed that a given mix of over-the-air stations is equivalent to a cable system with the same mix of stations in an area with no

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[145] Note that N is always less than or equal to N_p so $\ln(\frac{N}{N_p})$ in equation (B-1) is always less than or equal to zero.

over-the-air stations. That is, the quality of free television relative to no television can be expressed in terms of equation (B-2) as

(B-3)
$$T = (1+A^f)^a \, (1+I^f)^b$$

Substituting this expression into equation (B-1) gives an estimate of the maximum amount the Nth household in an area not passed by cable would be willing to pay for A^f unduplicated network and I^f independent over-the-air stations.

A. Value of Over-the-Air Television to Households Not Passed by Cable

To find the total value of free television one must add up the maximum amount each household is willing to pay. Integrating under the demand curve does this for a continuous distribution of households. In areas not passed by cable one must integrate under the entire demand curve (B-1) from N=0, which represents the household with the greatest willingness to pay, to N=N_p, which represents the one with the lowest. This gives total consumer surplus, W, for quality T free television as expressed in (B-3). That is:

(B-4)
$$W = Y\int_0^{N_p}[1-T(x)^{\ln(\frac{N}{N_p})}]\,dN$$

Performing the integration and evaluating the expression we get:[146]:

---

[146] This requires integrating the term $T(x)^{\ln(\frac{N}{N_p})}$ in equation (B-4). To do this we made the following substitutions suggested by Kathleen Levitz, which transforms the expression into a standard form with a well known integral. Let

$a = T(x)$, and

$t = \ln(\frac{N}{N_p})$,

so $dt = (1/N)dN$ or $dN = N\,dt$, and

$e^t = \frac{N}{N_p}$ or $N = N_p e^t$.

Thus $T(x)^{\ln(\frac{N}{N_p})}\,dN = a^t dN = a^t N_p e^t\,dt = N_p (ae)^t\,dt$.

Using the fact that (for a derivation see George Thomas, Calculus and Analytic Geometry, 4th ed. (Reading, Mass.: Addison-Wesley, 1968), p. 254.)

$$\int b^u du = \frac{b^u}{\ln b}$$

(B-5) $$W = N_p Y \frac{\ln T(x)}{1+\ln T(x)}$$

For example, for 4 network-affiliated stations and 12 independent stations the natural logarithm of *T(x)* is given by

$$\ln T(x) = .0385 \ln(1 + 4) + .0098 \ln(1 + 12) = .0871$$

Assuming a median household income of $30,853,[147] substituting this into (B-5) implies an average annual consumer surplus per household of

$$\frac{W}{N_p} = \$30{,}853 \left(\frac{.0871}{1+.0871}\right) = \$2{,}471.98$$

Repeating the calculation for 4 network-affiliated and 11 independent stations the average consumer surplus per household is $2,451.49. Thus the average annual welfare loss per household from taking an independent station off the air is the difference, which is about $20.49. This is the number we used in chapter IV for households not passed by cable.

B. Value of Over-the-Air Television to Households Passed by Cable But Not Subscribing

We assumed that for areas passed by cable, taking stations off the air affects only households not subscribing to cable. Suppose households N_s through N_p do not subscribe to cable. As indicated by the height of the demand curve in figure B-1, these households place a lower value on television than those that do subscribe to cable. To estimate the total amount these households would pay for a given quality of over-the-air television stations one can integrate under the demand curve for over-the-air television from N_s to N_p:

---

implies that $$N_p \int (ae)^t \, dt = \frac{N_p (ae)^t}{\ln(ae)} = \frac{N_p (a^t e^t)}{1+\ln a}.$$

Substituting the expressions for a and t into the above expression implies that

$$\int T(x)^{\ln(\frac{N}{N_p})} dN = \frac{N T(x)^{\ln(\frac{N}{N_p})}}{1+\ln T(x)}.$$

147 1987 national median family income. Council of Economic Advisers, Economic Report of the President, 1989, p. 342.

(B-6) $$W = Y \int_{N_s}^{N_p} [1 - T(x)^{\ln(\frac{N}{N_p})}]\, dN$$

(B-7) $$= N_p Y \left[\frac{\ln T(x)}{1 + \ln T(x)} - s\,\frac{1 - T(x)^{\ln(s)}}{1 + \ln T(x)}\right]$$

where

$$s = \frac{N_s}{N_p}$$, the share of households subscribing.

The estimates given in chapter IV for households passed by cable but choosing not to subscribe were derived from this formula. For example, we estimated that in 1992 such households in Los Angeles would be willing to pay an average of $5.98 annually for a twelfth independent over-the-air station. This was derived using the following assumptions:

N_p = 4.35 million (households passed by cable)

N_s = 2.48 million (households subscribing to cable)

Y = $30,853 (median family income).

This implies that

$s = N_s/N_p = .57$ (share of households passed subscribing)

$\ln s = -.5616.$

Assuming 4 network-affiliated stations and 12 independent stations we have

$T(x) = (1 + 4)^{.0385}(1 + 12)^{.0098} = 1.09101$ (quality measure)

$\ln T(x) = .0871$

$T(x)^{\ln(s)} = .95224.$

Substituting these expressions into equation (B-7) we get total consumer surplus

$$W = (4.35)(\$30,853)\{[.0871/(1 + .0871)] - (.57)[1 - .95224/(1 + .0871)]\}$$

$$= \$1,260.71 \text{ million.}$$

To find the loss from removing one independent station we repeat the calculation for 4 network-affiliated stations and 11 independents. Under these assumptions, $T(x) = 1.09015$ and $W = \$1,249.53$ million. Subtracting W from the same expression in the previous case we get a loss of consumer surplus of $11.18 million. Dividing this by the 1.87 million households passed by cable but not subscribing, implies an average annual loss in consumer surplus of $5.98 from taking one independent station off the air.

APPENDIX C:
EXISTING AND PROPOSED USES OF THE UHF TELEVISION BAND WITHIN 200 MILES OF LOS ANGELES

FULL POWER TELEVISION STATIONS LESS THAN 40 MILES FROM LOS ANGELES

CHN	SVC	LAT	LNG	DIS
18	BTC	34.1875	117.698332.	45
22	BTC	34.2267	118.0664	15.54
28	BTE	34.2239	118.0622	15.55
30	BTC	34.1875	117.6994	32.39
34	BTC	34.2264	118.0656	15.56
40	BTC	34.2242	118.0622	15.57
46	BTC	34.2269	118.0661	15.56
50	BTE	33.9719	117.9492	17.67
52	BTC	34.2242	118.0625	15.56
56	BTC	34.1872	117.7003	32.33
58	BTE	34.2239	118.0625	15.54
62	BTC	34.1875	117.6983	32.45
68	BTE	34.2267	118.0664	15.54

FULL POWER TELEVISION STATIONS AND VACANT ALLOTMENTS BETWEEN 40 AND 200 MILES OF LOS ANGELES

CHN	SVC	LAT	LNG	DIS
15	BTE	32.6964	116.9353	119.80
17	BTC	35.4389	118.7397	99.57
18	BTE	36.7458	119.2811	194.76
21	BTC	36.3	119.61	73.21
23	BTC	35.4539	118.5936	98.51
24	BTC	36.7458	119.2814	194.76
24	BTE	33.9658	117.2847	55.17
26	BTC	36.6672	118.8783	183.66
27	BTE	36.3047	120.4022	198.46
29	BTC	35.4531	118.5903	98.42
31	BTC	34.1928	116.1061	122.78
33	BTC	35.3	120.7	165.05
36	BTC	33.8667	116.4322	104.52
38	BTC	34.4	119.7	86.97
39	BTC	32.6967	116.935	119.80
42	BTC	33.8661	116.4339	104.42
43	BTC	36.7458	119.2811	194.76
44	BTC	33.3867	18.4	46.87
45	BTC	35.4389	118.74	99.58
49	BTE	36.2872	118.8381	157.58
51	BTC	34.28	119.29	62.12
51	BTC	32.6978	116.9339	119.78

54	BTC	33.3867	118.4	46.87
57	BTC	34.3028	119.228	59.12
59	BTC	34.21	116.85	80.48
61	BTC	36.0581	118.7844	141.51
63	BTC	34.3303	119.0233	48.71
64	BTC	34.6094	117.2864	66.78
69	BTC	32.6964	116.9353	119.80

HYPOTHETICAL ATV ALLOTMENTS WITHIN 200 MILES OF LOS ANGELES

CHN	SVC	LAT	LNG	DIS
16	BTC	32.4725	115.3244	199.59
18	BTC	34.3303	119.0233	48.71
22	BTC	32.6967	116.935	119.80
24	BTC	34.1647	119.1719	53.91
25	BTC	32.6978	116.9339	119.78
25	BTC	34.0327	118.15	5.43
26	BTC	33.8661	116.4339	104.42
26	BTC	34.3028	119.228	59.12
27	BTC	34.0327	118.15	5.43
28	BTC	32.6964	116.9353	119.80
29	BTC	34.1875	117.6983	32.45
30	BTC	34.2517	119.4154	68.69
31	BTC	33.3867	118.4	46.87
32	BTC	34.2517	119.4154	68.69
35	BTC	34.1875	117.6994	32.39
36	BTC	33.3867	118.4	46.87
38	BTC	34.1875	117.6983	32.45
39	BTC	34.6094	117.2864	66.78
41	BTC	34.0327	118.15	5.43
43	BTC	34.0327	118.15	5.43
44	BTC	34.21	116.85	80.48
45	BTC	34.0327	118.15	5.43
47	BTC	34.0327	118.15	5.43
49	BTC	34.2267	118.0664	15.54
55	BTC	34.2264	118.0656	15.56
23	BTE	33.9719	117.949	17.68
32	BTE	33.9658	117.2847	55.17
53	BTE	34.2239	118.0622	15.55
60	BTE	34.2239	118.0625	15.54
65	BTE	34.2267	118.0664	15.54

EXISTING LAND MOBILE SHARING CHANNELS IN LOS ANGELES

CHN	SVC	LAT	LNG	DIS
14	LM	34.05417	118.2411	0.00
16	LM	34.05417	118.2411	0.00

20	LM	34.05417	118.2411	0.00

PROPOSED LAND MOBILE SHARING CHANNELS IN LOS ANGELES

CHN	SVC	LAT	LNG	DIS
26	LM	34.05417	118.2411	0.00
32	LM	34.05417	118.2411	0.00
36	LM	34.05417	118.2411	0.00
42	LM	34.05417	118.2411	0.00
48	LM	34.05417	118.2411	0.00
60	LM	34.05417	118.2411	0.00
66	LM	34.05417	118.2411	0.00

RADIOASTRONOMY CHANNEL

CHN	SVC	LAT	LNG	DIS
37	RA	34.05417	118.2411	0.00

LOW POWER TELEVISION STATIONS WITHIN 200 MILES OF LOS ANGELES

CHN	SVC	LAT	LNG	DIS
14	BTR	34.065	116.545	97.25
14	BTR	35.6622	117.6033	116.64
15	BTR	35.3606	120.6558	165.12
15	BTR	34.4631	116.8789	83.03
15	BTR	36.2853	118.8386	157.46
15	BTR	34.8853	116.8958	96.06
16	BTR	34.065	116.545	97.25
19	BTR	34.8853	116.8958	96.06
19	BTR	33.3083	116.8389	95.41
19	BTR	36.2047	115.9639	197.46
19	BTR	34.4631	116.8789	83.03
20	BTR	35.1525	118.5805	78.12
20	BTR	34.0461	116.8136	81.85
21	BTR	32.8622	115.5614	174.20
21	BTR	34.6108	117.2867	66.82
23	BTR	34.8853	116.8958	96.06
24	BTR	34.4103	119.7072	87.57
24	BTR	36.2047	115.9639	197.46
25	BTR	34.1364	116.1686	118.96
25	BTR	34.6108	117.2867	66.82
26	BTR	34.1489	116.445	103.19
26	BTR	34.4603	119.8156	94.51
27	BTR	34.6108	117.2867	66.82
31	BTR	34.6108	117.2867	66.82
33	BTR	34.61	117.2869	66.78
33	BTR	34.4411	119.2828	65.40
33	BTR	35.1525	118.5805	78.12

33	BTR	35.3131	119.0403	98.08
35	BTR	34.8853	116.8958	96.06
35	BTR	35.1525	118.5805	78.12
36	BTR	34.4708	119.6758	87.12
36	BTR	36.2047	115.9639	197.46
36	BTR	35.3606	120.6558	165.12
38	BTR	34.125	116	128.59
38	BTR	34.125	116	128.59
39	BTR	35.1525	118.5805	78.12
39	BTR	35.4539	118.5936	98.51
41	BTR	35.1525	118.5805	78.12
41	BTR	34.4631	116.8789	83.03
43	BTR	35.4747	117.6992	102.66
44	BTR	34.9708	117.0394	93.46
44	BTR	35.1425	120.5194	150.61
45	BTR	35.1694	118.625	79.91
47	BTR	34.273	119.2683	60.79
47	BTR	35.48	117.683	103.30
47	BTR	34.6097	117.2867	66.77
48	BTR	35.1694	118.625	79.91
48	BTR	33.0086	116.9711	102.42
48	BTR	34.4631	116.8789	83.03
49	BTR	34.4708	119.6758	87.12
49	BTR	35.48	117.683	103.30
49	BTR	33.2147	117.1875	83.62
50	BTR	36.5389	117.7875	173.12
51	BTR	34.6108	117.2867	66.82
51	BTR	35.1694	118.625	79.91
52	BTR	36.5308	117.7889	172.55
53	BTR	33.61	116.4408	107.66
53	BTR	35.48	117.683	103.30
53	BTR	34.5253	119.9581	103.66
54	BTR	35.1694	118.625	79.91
54	BTR	36.5389	117.7875	173.12
54	BTR	34.4631	116.8789	83.03
54	BTR	34.0755	115.955	131.08
54	BTR	34.4631	116.8789	83.03
55	BTR	34.5253	119.9581	103.66
55	BTR	34.0861	118.7758	30.74
55	BTR	33.5583	116.5194	104.46
55	BTR	34.6108	117.2867	66.82
55	BTR	35.48	117.683	103.30
55	BTR	35.4389	118.7397	99.57
56	BTR	36.5389	117.7875	173.12
56	BTR	35.1356	118.6639	78.34

57	BTR	34.0044	119.6483	80.76
57	BTR	33.0086	116.9711	102.42
57	BTR	35.3606	120.6558	165.12
57	BTR	36.2853	118.8386	157.46
57	BTR	35.48	117.683	103.30
58	BTR	36.5389	117.7875	173.12
58	BTR	35.4389	118.7397	99.57
59	BTR	34.4631	116.8789	83.03
59	BTR	33.8475	116.8514	80.94
59	BTR	35.48	117.683	103.30
59	BTR	32.8789	117.2425	99.15
59	BTR	34.155	116.2017	117.14
59	BTR	34.4653	119.6772	87.07
60	BTR	34.065	116.545	97.25
60	BTR	34.0461	116.8136	81.85
60	BTR	35.1356	118.6639	78.34
61	BTR	34.8853	116.8958	96.06
61	BTR	34.155	116.2017	117.14
61	BTR	34.8853	116.8958	96.06
61	BTR	35.48	117.683	103.30
61	BTR	34.4661	119.6769	87.08
61	BTR	34.4103	119.7072	87.57
61	BTR	35.3058	120.6222	161.47
62	BTR	35.1356	118.6639	78.34
62	BTR	34.968	120.5686	147.55
62	BTR	34.5472	118.2067	34.02
62	BTR	34.065	116.545	97.25
62	BTR	32.8472	117.2736	99.94
63	BTR	34.0755	115.955	131.08
63	BTR	35.48	117.683	103.30
64	BTR	34.065	116.545	97.25
65	BTR	34.4661	119.6769	87.08
65	BTR	34.8325	120.3819	133.94
65	BTR	34.0755	115.955	131.08
65	BTR	34.4661	119.6769	87.08
65	BTR	34.775	118.9683	64.84
65	BTR	35.48	117.683	103.30
66	BTR	33.8672	116.4369	104.24
66	BTR	35.0581	120.5294	148.31
66	BTR	36.2047	115.9639	197.46
66	BTR	35.1356	118.6639	78.34
67	BTR	34.8853	116.8958	96.06
67	BTR	34.0755	115.955	131.08
67	BTR	34.065	116.545	97.25
67	BTR	34.8853	116.8958	96.06

67	BTR	35.48	117.683	103.30
67	BTR	34.3722	119.4203	71.07
67	BTR	32.8461	117.2758	99.94
68	BTR	34.4631	116.8789	83.03
68	BTR	35.0578	120.5294	148.30
68	BTR	35.1356	118.6639	78.34
69	BTR	34.8853	116.8958	96.06
69	BTR	34.1961	117.0333	69.94
69	BTR	35.3058	120.6222	161.47
69	BTR	35.48	117.683	103.30

MEXICAN FULL POWER TELEVISION STATIONS AND ALLOTMENTS WITHIN 200 MILES OF LOS ANGELES

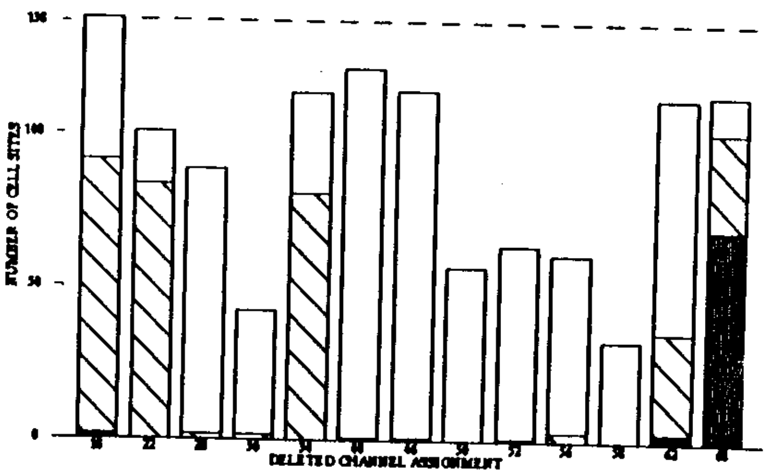
CHN	SVC	LAT	LNG	DIS
14	BTM	32.65	115.4667	186.17
17	BTM	31.86667	116.6083	177.39
20	BTM	32.65	115.4667	186.17
21	BTM	32.53056	117.0294	125.86
23	BTM	31.86667	116.6083	177.39
27	BTM	32.50917	117.0294	127.09
29	BTM	31.83333	116.6083	179.35
32	BTM	32.65	115.4667	186.17
33	BTM	32.53056	117.0294	125.86
35	BTM	31.9	116.6669	173.68
38	BTM	32.65	115.4667	186.17
41	BTM	31.9	116.6669	173.68
45	BTM	32.53056	117.0294	125.86
49	BTM	32.575	116.625	137.72
57	BTM	32.53056	117.0294	125.86
61	BTM	31.9	116.6669	173.68
66	BTM	32.65	115.4667	186.17
67	BTM	32.575	116.625	137.72

APPENDIX D

FREQUENCY BANDWIDTH TECHNICALLY USABLE FOR CELLULAR SERVICE AT WIRELINE SYSTEM CELL SITES WITHIN 104.6 MILES OF LOS ANGELES AFTER THE DELETION OF INDIVIDUAL UHF TELEVISION ASSIGNMENTS WITHIN 40 MILES OF LOS ANGELES (MEXICAN STATIONS INCLUDED)

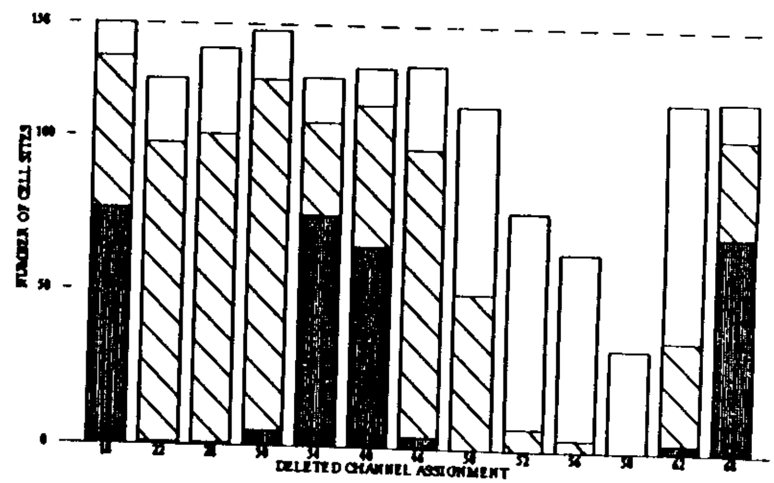
Scenario 1
(Existing and Proposed Uses Protected)

BANDWIDTH AVAILABLE	NUMBER OF CELL SITES HAVING THIS AMOUNT OF BANDWIDTH AVAILABLE AFTER DELETION OF ASSIGNMENT ON CHANNEL:												
AT SITE	18	22	28	30	34	40	46	50	52	56	58	62	66
0 MHZ	0	37	49	96	24	16	23	81	74	77	105	25	24
6 MHZ	46	17	87	40	33	121	114	57	63	58	33	77	12
12 MHZ	90	84	2	2	81	1	0	0	1	3	0	33	32
18 MHZ	2	0	0	0	0	0	1	0	0	0	0	3	70



Scenario 2
(Existing Uses Protected)

BANDWIDTH AVAILABLE	NUMBER OF CELL SITES HAVING THIS AMOUNT OF BANDWIDTH AVAILABLE AFTER DELETION OF ASSIGNMENT ON CHANNEL:												
AT SITE	18	22	28	30	34	40	46	50	52	56	58	62	66
0 MHZ	0	19	9	3	18	15	14	27	61	74	105	25	24
6 MHZ	12	21	28	16	15	12	27	61	70	60	33	77	12
12 MHZ	49	97	100	114	30	46	93	50	7	4	0	33	32
18 MHZ	77	1	1	5	75	65	4	0	0	0	0	3	70



NOTES:

1. Each bar represents the column of data directly above it.
2. There are 138 wireline system cell sites within the 104.5 mile study radius.
3. Scenario 1 assumes protection of existing full power television assignments and vacant allotments, existing low power assignments, current and proposed land mobile sharing channels, and the hypothetical ATV allotments.
4. Scenario 2 assumes protection of existing full power television assignments, and vacant allotments, existing low power assignments and current land mobile sharing channels.
5. This chart is the same as figure 6 in paper except that Mexican television stations and vacant allotments were included in the database when this chart was produced.

APPENDIX E: COMPUTER MAPS SHOWING POTENTIAL CELLULAR SPECTRUM AVAILABILITY WITHIN 104.5 MILES OF LOS ANGELES AFTER THE DELETION OF INDIVIDUAL UHF TELEVISION STATIONS WITHIN 40 MILES OF LOS ANGELES

Contents: .... Pages

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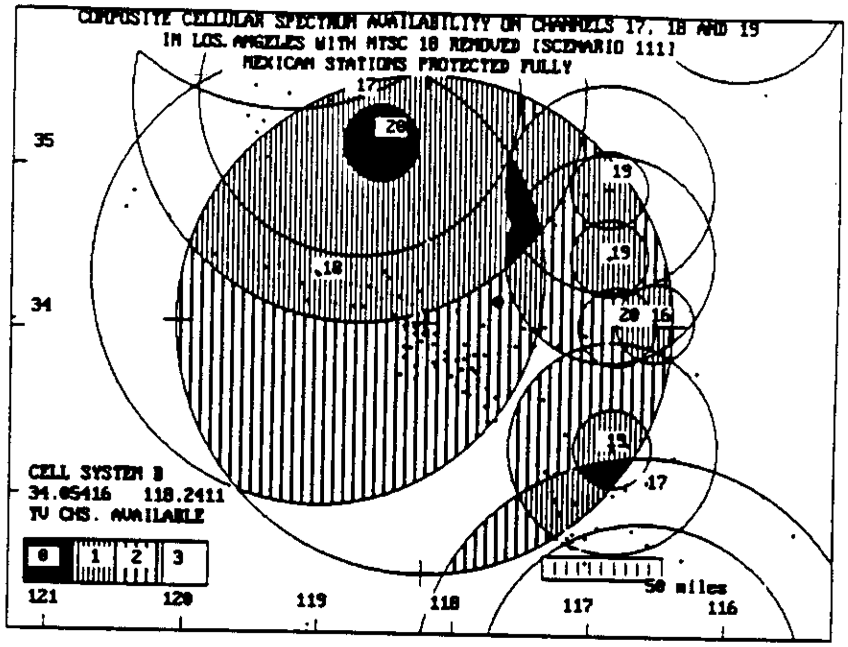
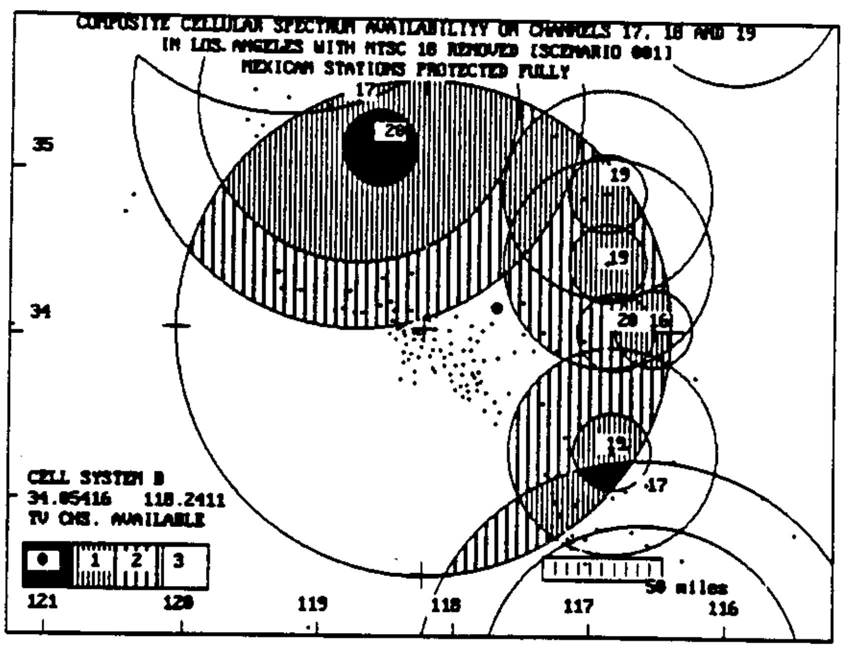
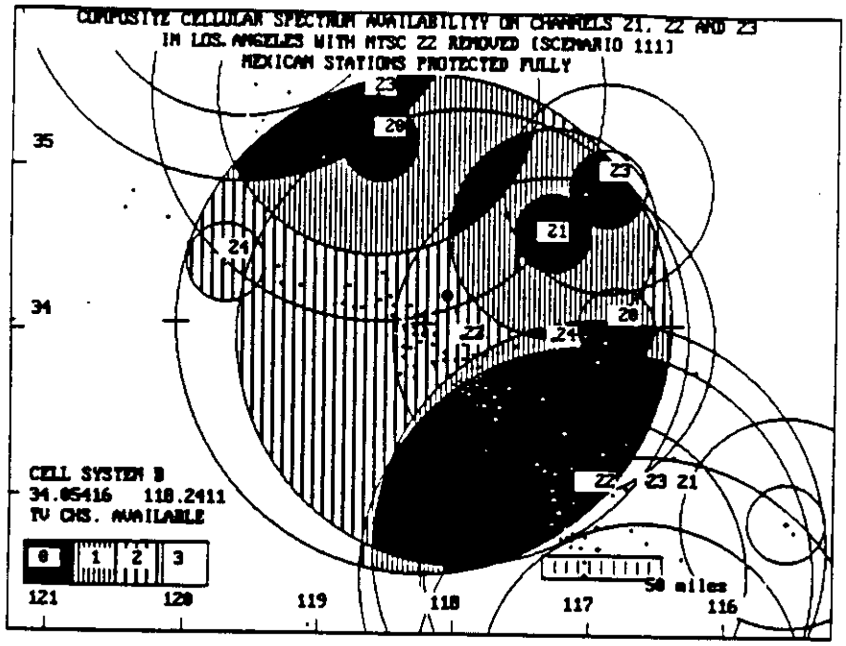
[147] Scenario 1 (the top map on each page) protects existing full power television assignments and allotments, existing low power television assignments, current and proposed land mobile sharing channels, and hypothetical ATV allotments. Scenario 2 (bottom map) protects existing full power television assignments and allotments, existing low power television assignments and current land mobile sharing channels.

[148] Highest social value as shown in figure 11 in body of paper.


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 17, 18 AND 19
IN LOS ANGELES WITH NTSC 18 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
1
2
3
121
120
119
118
117
116
50 miles


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 17, 18 AND 19
IN LOS ANGELES WITH NTSC 18 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
1
2
3
121
120
119
118
117
116
50 miles


COMPOSITYE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 21, 22 AND 23
IN LOS ANGELES WITH NTSC 22 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
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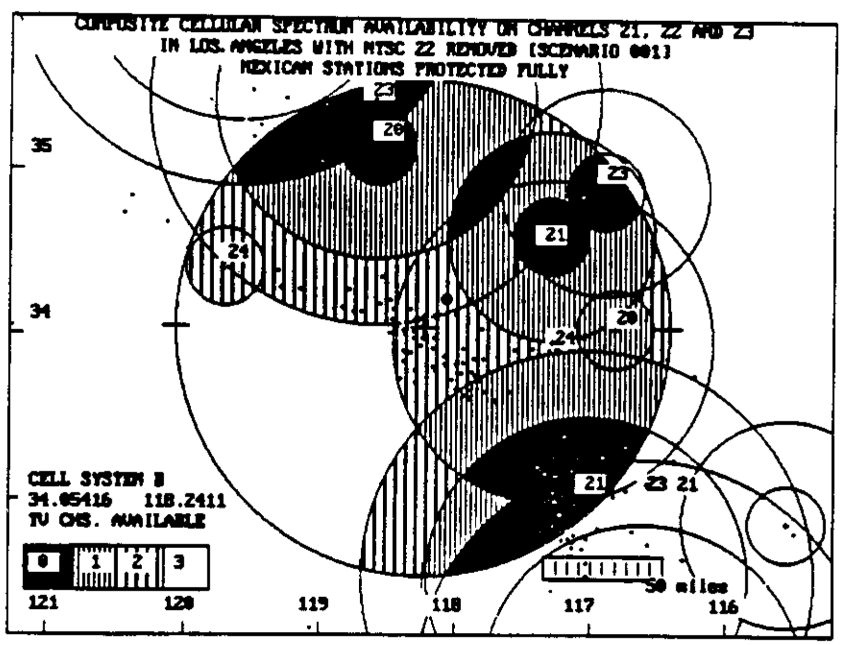
50 miles
121
120
119
118
117
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 21, 22 AND 23
IN LOS ANGELES WITH NTSC 22 REMOVED (SCENARIO 001)
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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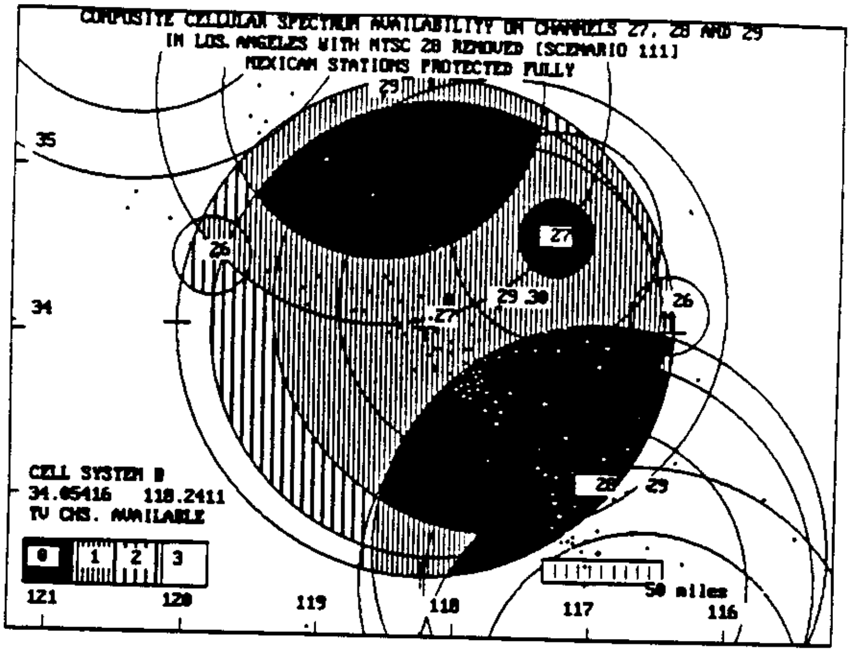
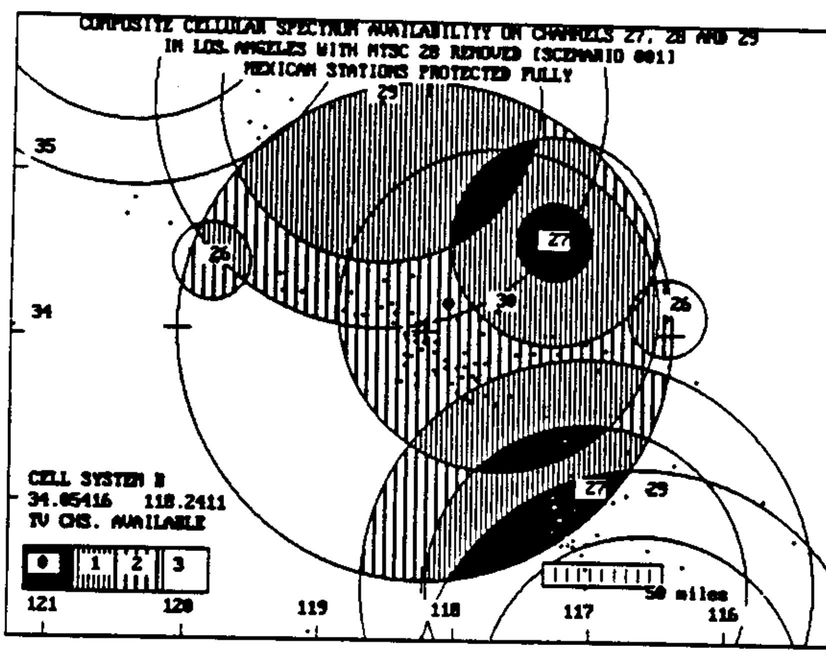
50 miles
121
120
119
118
117
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 27, 28 AND 29
IN LOS ANGELES WITH NTSC 28 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
35
34
26
27
29 30
28
29
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0 1 2 3
50 miles
121 120 119 118 117 116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 27, 28 AND 29
IN LOS ANGELES WITH NTSC 28 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
35
34
26
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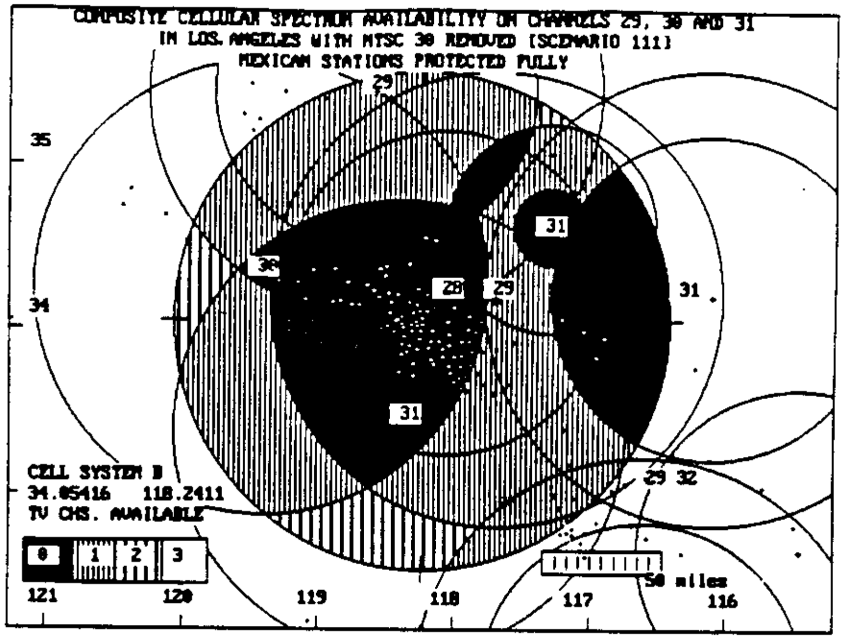
30
29
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0 1 2 3
50 miles
121 120 119 118 117 116



COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 29, 30 AND 31
IN LOS ANGELES WITH NTSC 30 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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121
120
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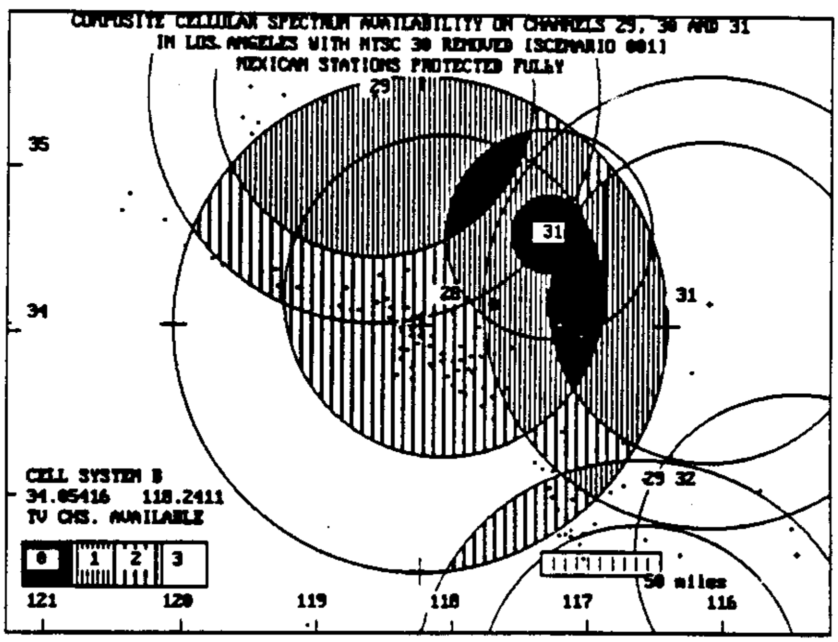
116



COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 29, 30 AND 31
IN LOS ANGELES WITH NTSC 30 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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121
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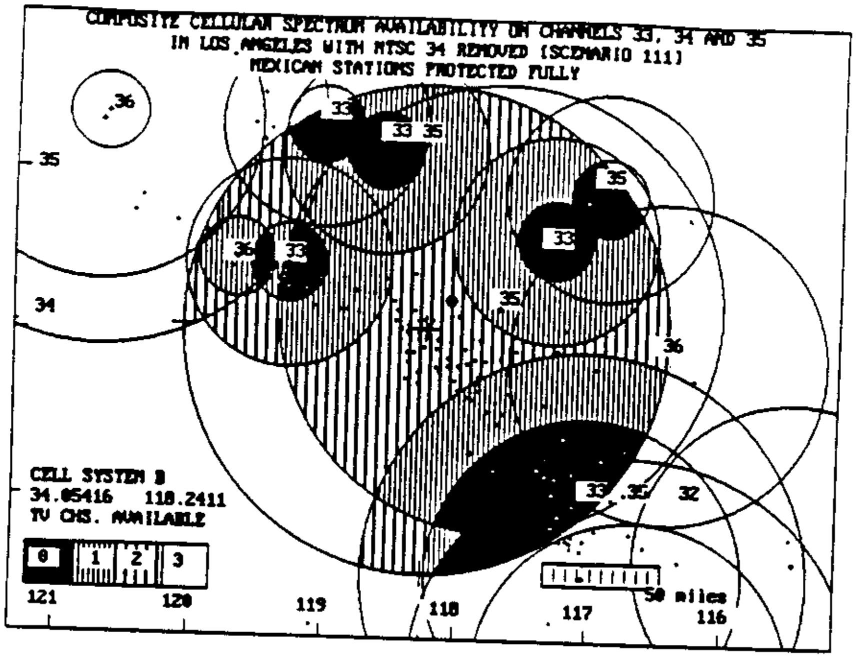
COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 33, 34 AND 35
IN LOS ANGELES WITH NTSC 34 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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120
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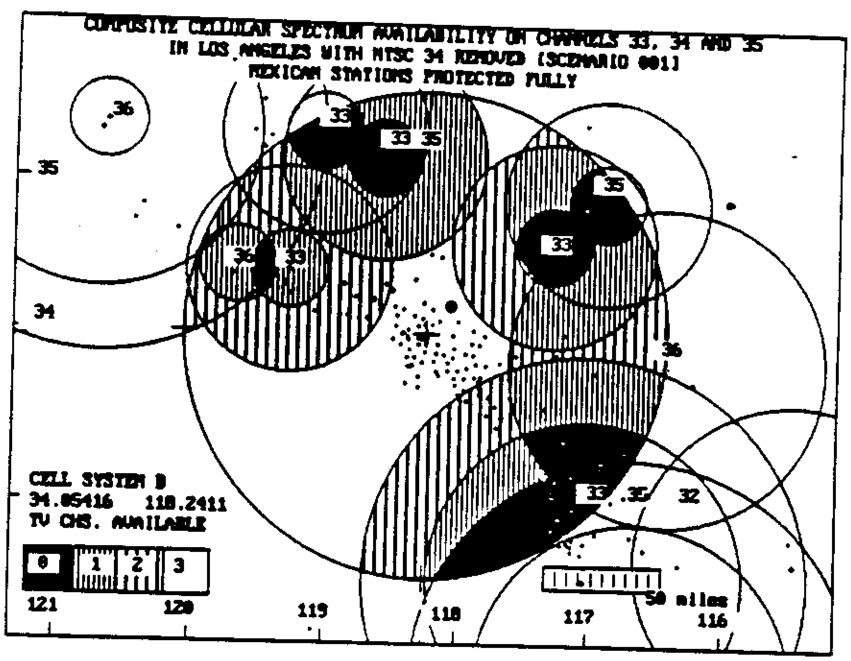
117
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 33, 34 AND 35
IN LOS ANGELES WITH NTSC 34 REMOVED (SCENARIO 001)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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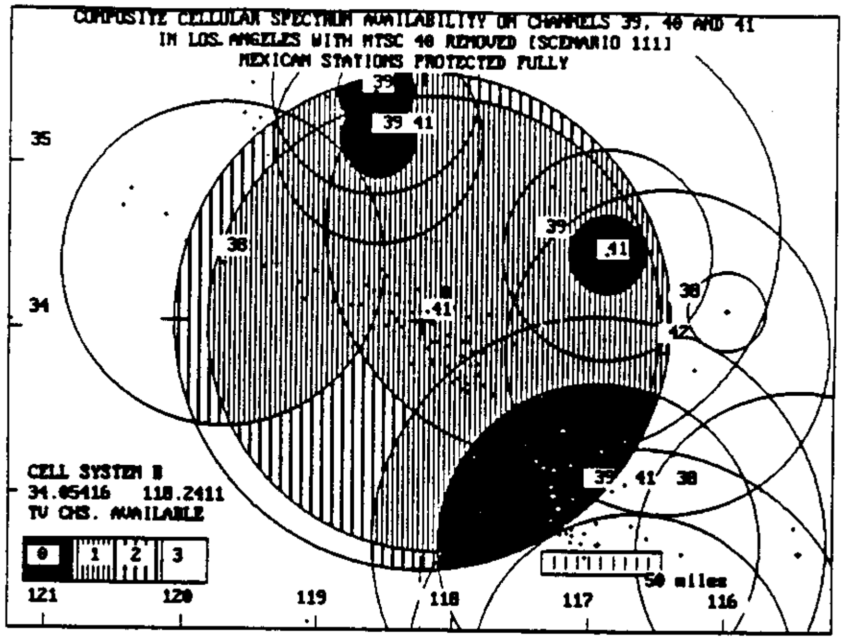
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 39, 40 AND 41
IN LOS ANGELES WITH NTSC 40 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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121
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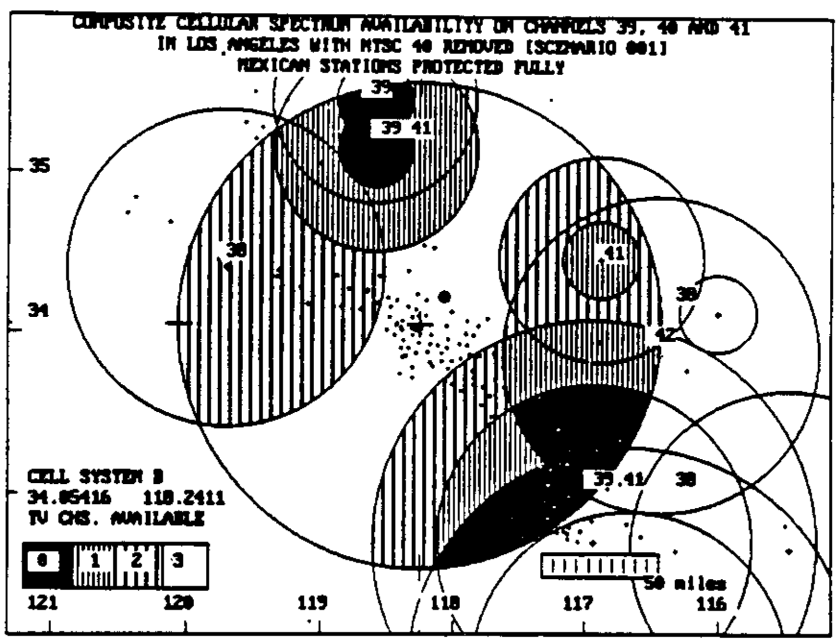
COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 39, 40 AND 41
IN LOS ANGELES WITH NTSC 40 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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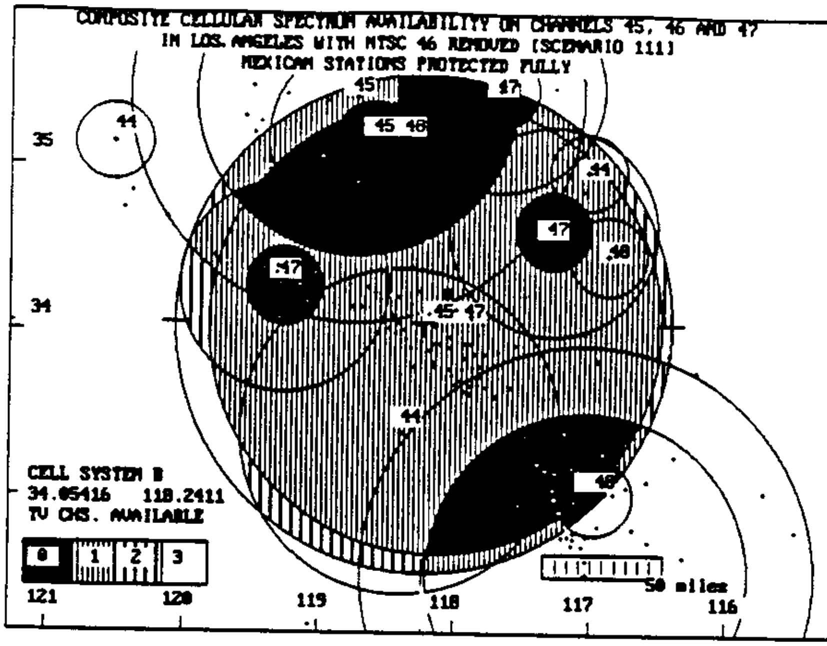
COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 45, 46 AND 47
IN LOS ANGELES WITH NTSC 46 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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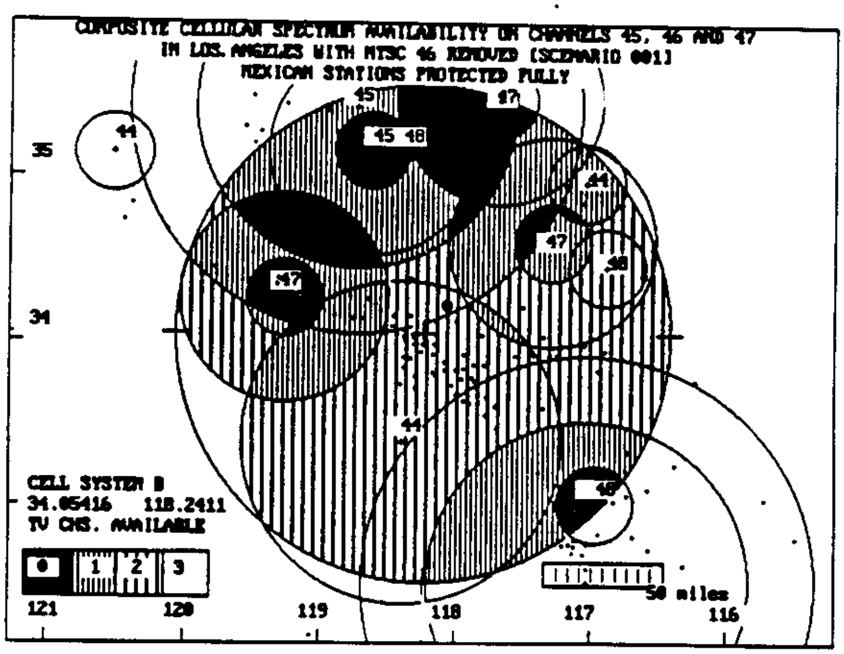
COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 45, 46 AND 47
IN LOS ANGELES WITH NTSC 46 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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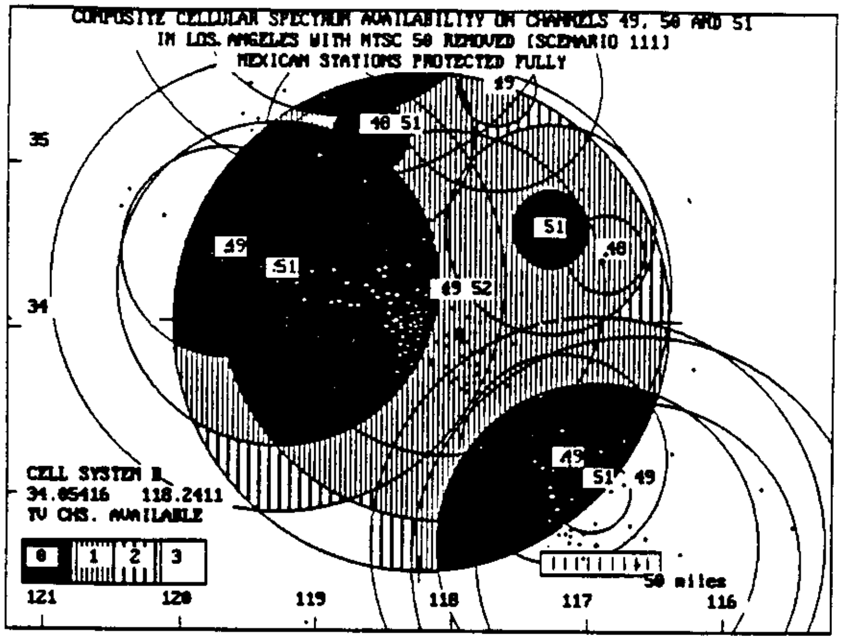
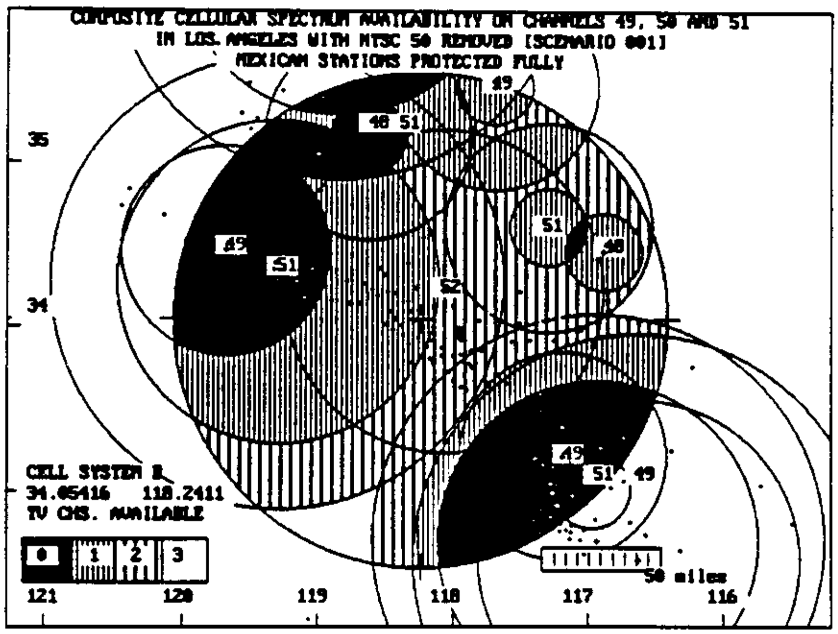
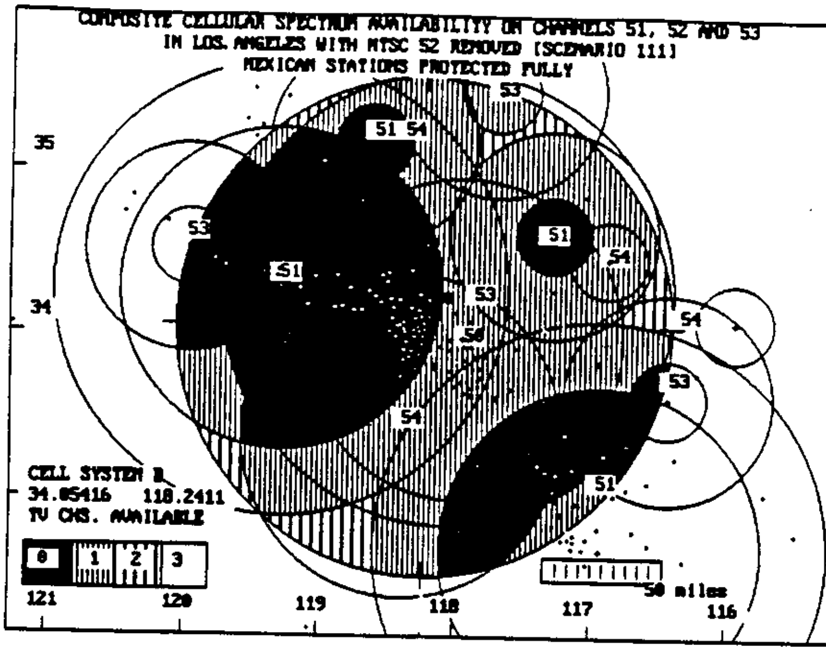
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 49, 50 AND 51
IN LOS ANGELES WITH NTSC 50 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0 1 2 3
50 miles
121 120 119 118 117 116
35
34


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 49, 50 AND 51
IN LOS ANGELES WITH NTSC 50 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0 1 2 3
50 miles
121 120 119 118 117 116
35
34


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 51, 52 AND 53
IN LOS ANGELES WITH NTSC 52 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0 1 2 3
50 miles
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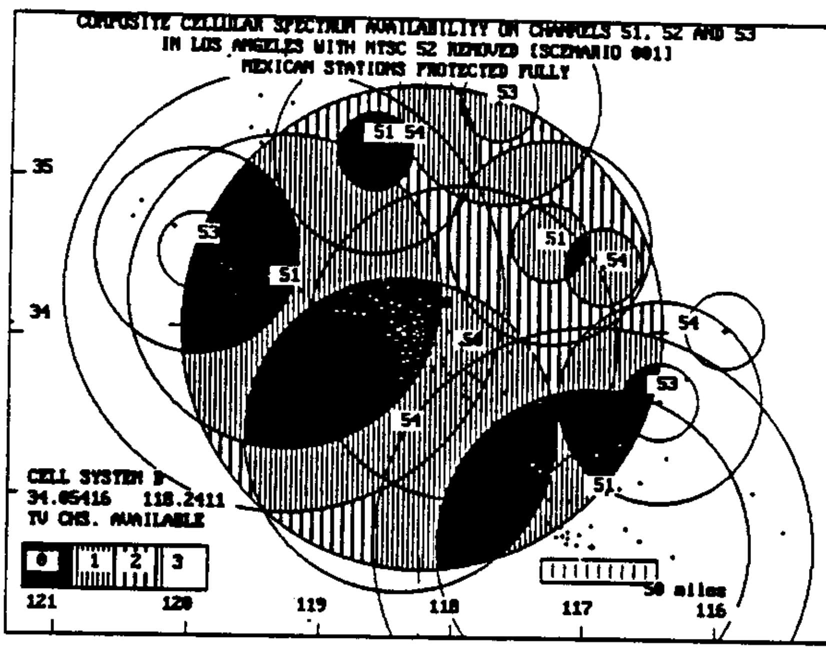
118
117
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 51, 52 AND 53
IN LOS ANGELES WITH NTSC 52 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0 1 2 3
50 miles
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121
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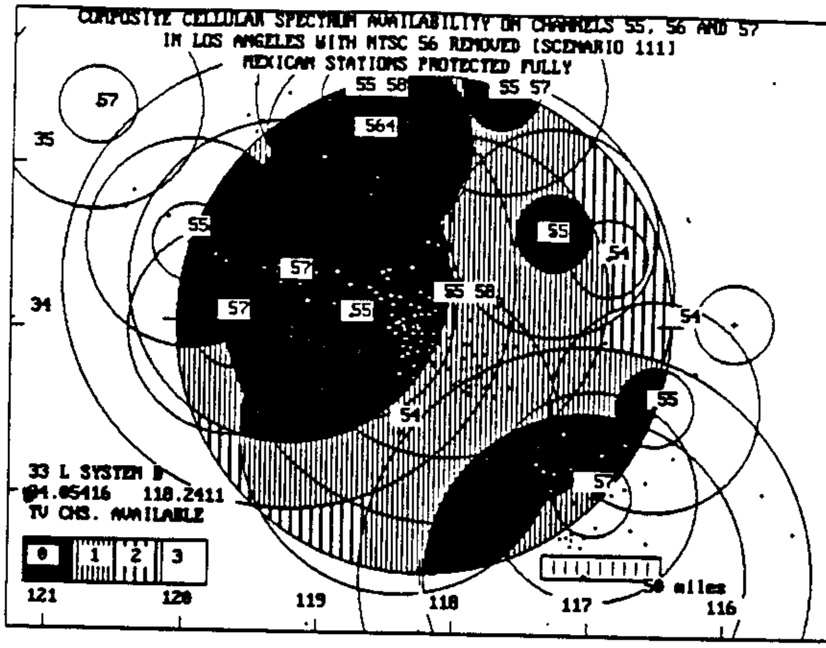
119
118
117
116


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 55, 56 AND 57
IN LOS ANGELES WITH NTSC 56 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
33 L SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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118
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116
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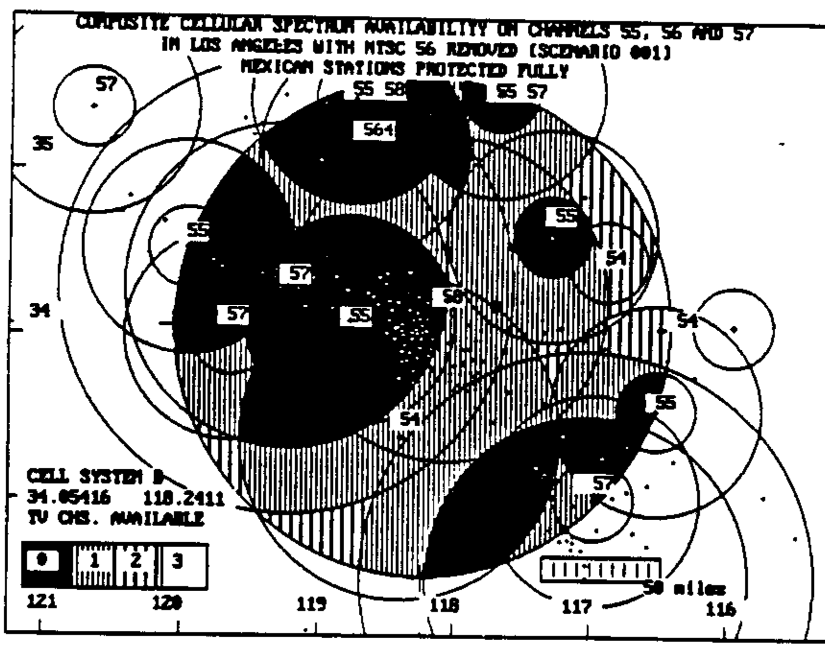
COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 55, 56 AND 57
IN LOS ANGELES WITH NTSC 56 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
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116
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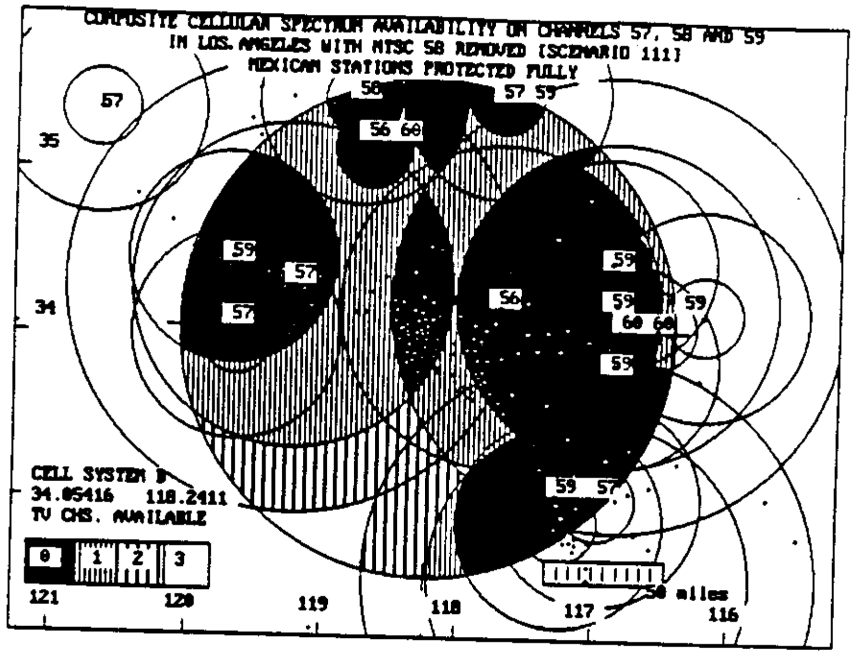
COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 57, 58 AND 59
IN LOS ANGELES WITH NTSC 58 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
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50 miles
121
120
119
118
117
116
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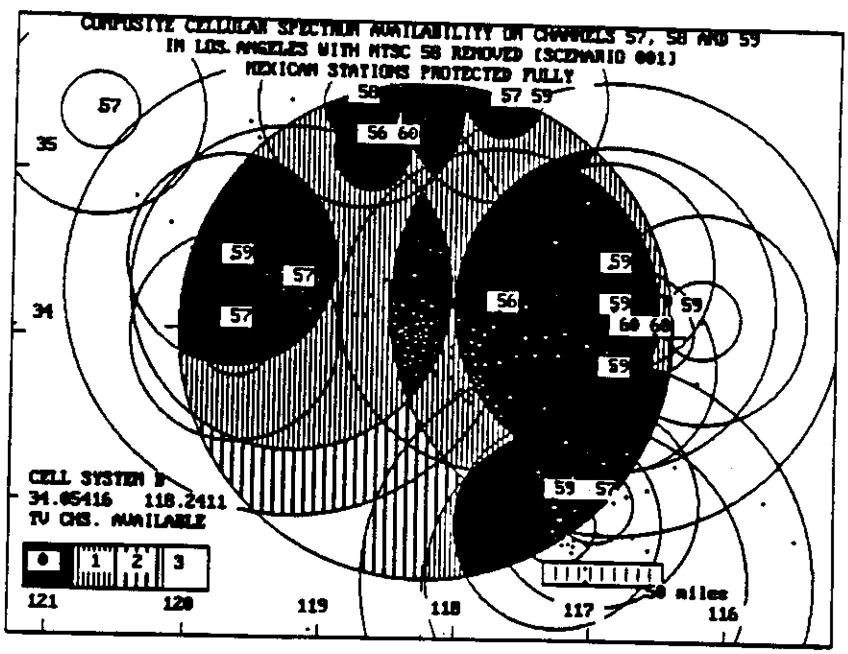
34


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 57, 58 AND 59
IN LOS ANGELES WITH NTSC 58 REMOVED (SCENARIO 001)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
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50 miles
121
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119
118
117
116
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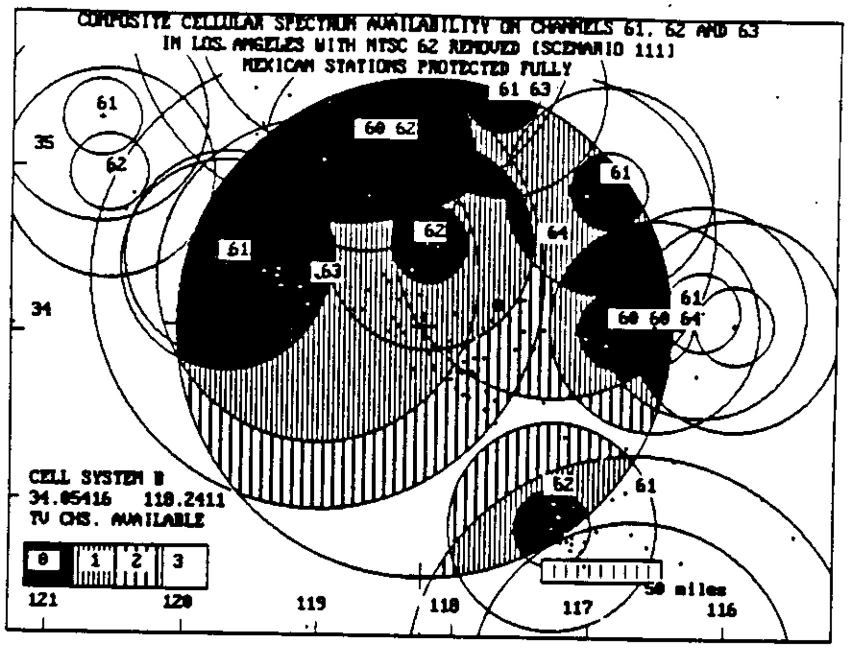
34


COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 61, 62 AND 63
IN LOS ANGELES WITH NTSC 62 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
61 63
60 62
61
62
35
61
62
64
61
63
34
61
60 60 64
62
61
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
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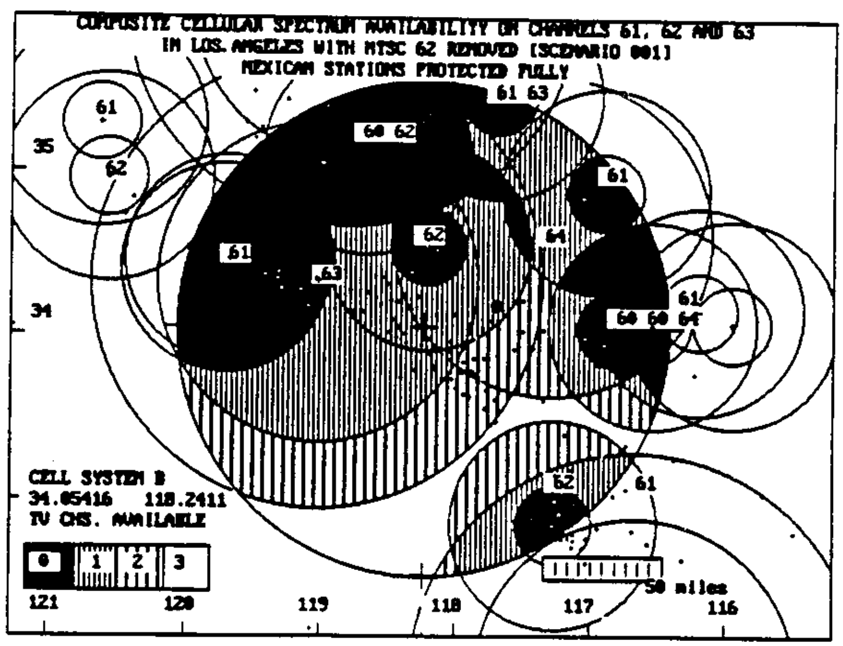
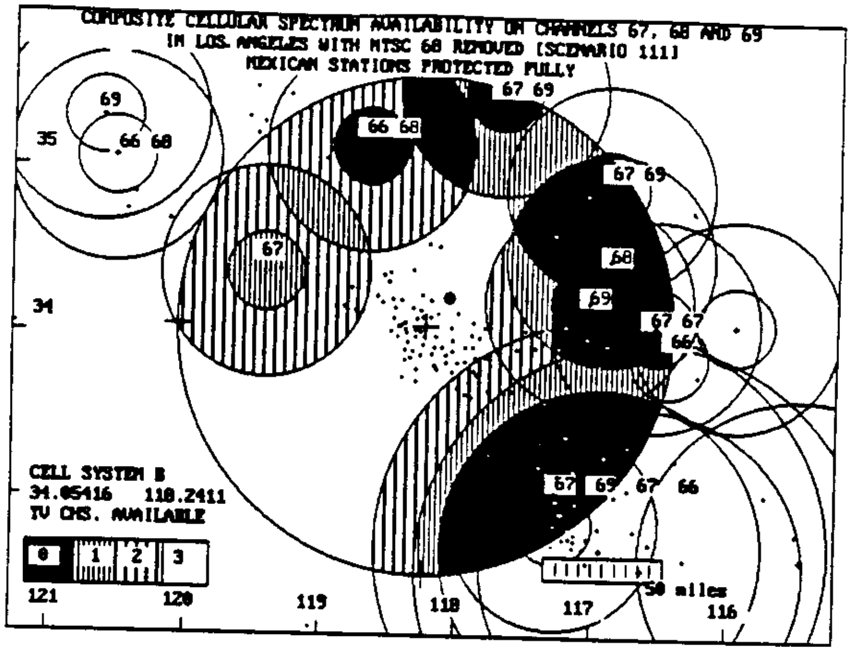
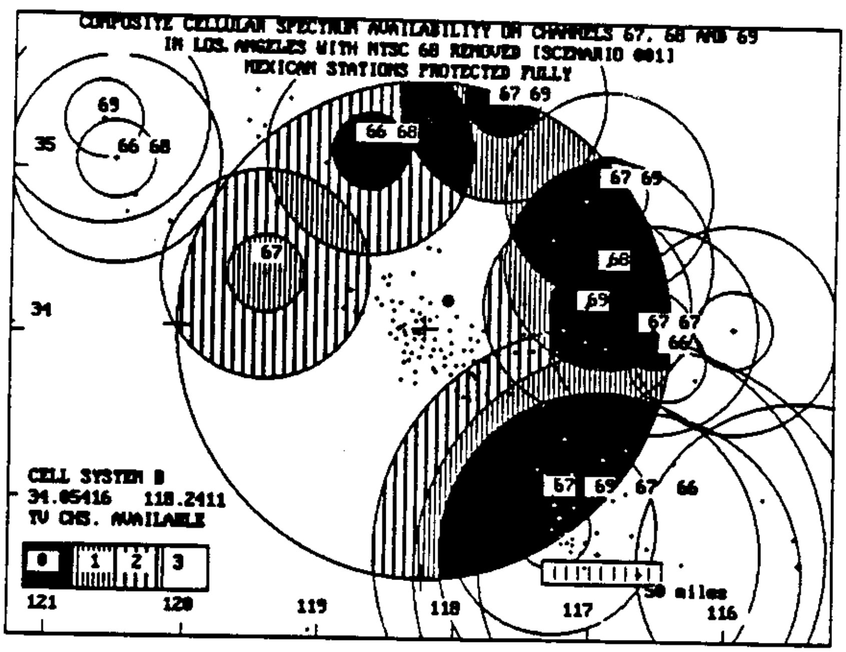
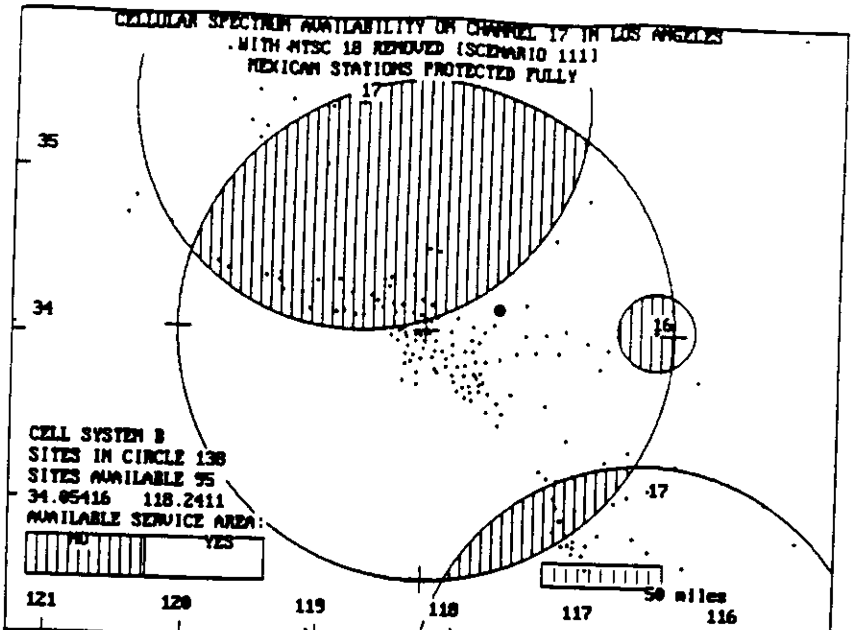
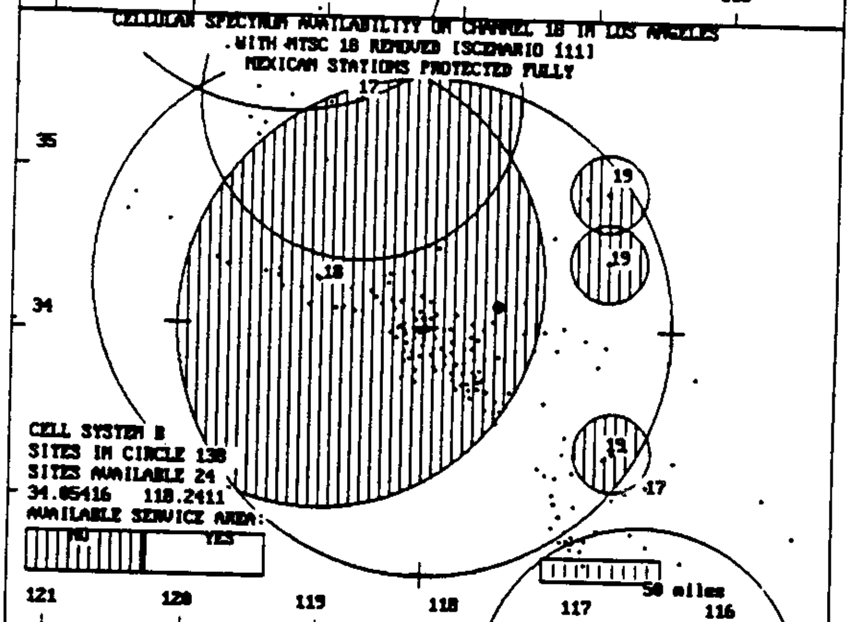
50 miles
121
120
119
118
117
116

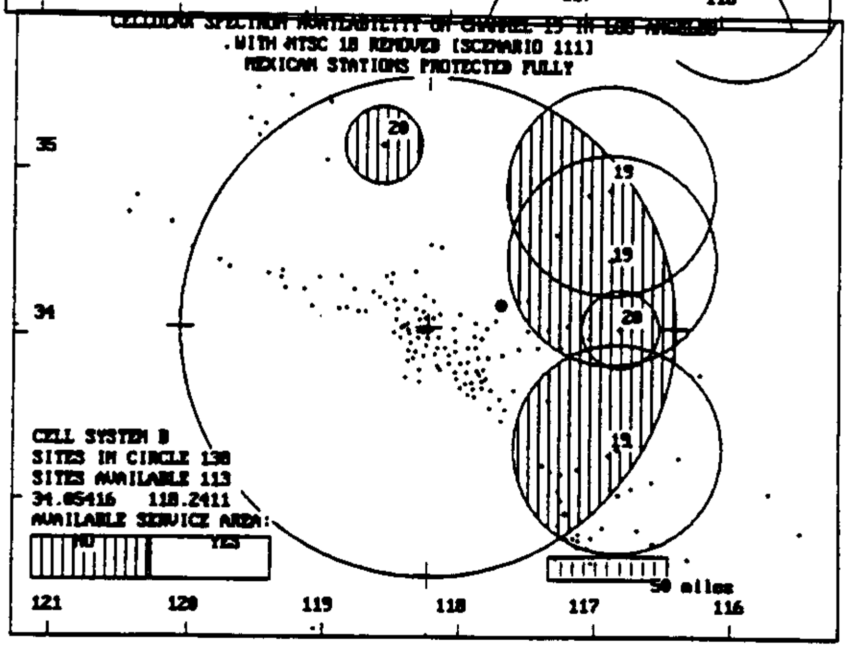

COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 61, 62 AND 63
IN LOS ANGELES WITH NTSC 62 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
61 63
60 62
61
62
35
61
62
64
61
63
34
61
60 60 64
62
61
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
1
2
3
50 miles
121
120
119
118
117
116

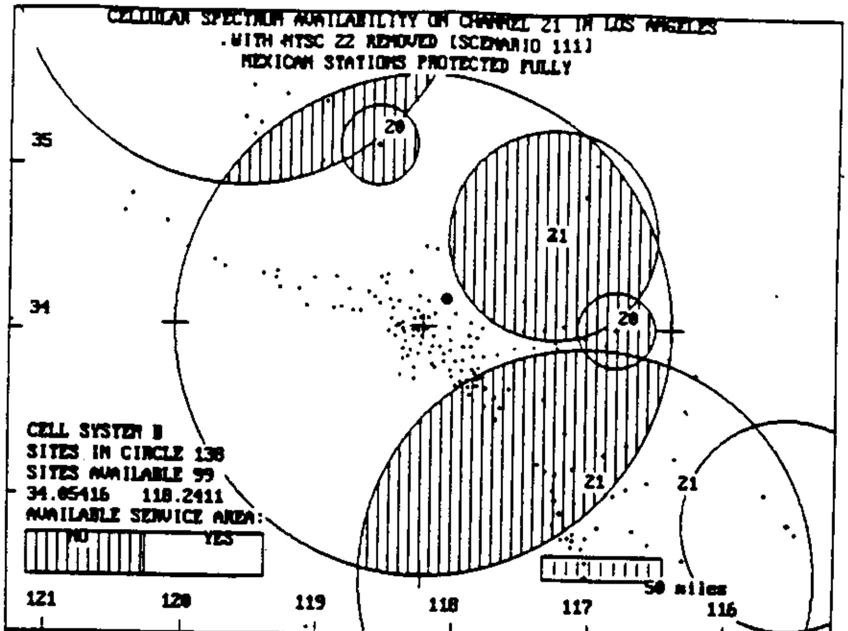

COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 67, 68 AND 69
IN LOS ANGELES WITH NTSC 68 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
67 69
69
35
66 68
66 68
67 69
67
68
34
69
67 67
66
67
69
67
66
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
1
2
3
50 miles
121
120
119
118
117
116

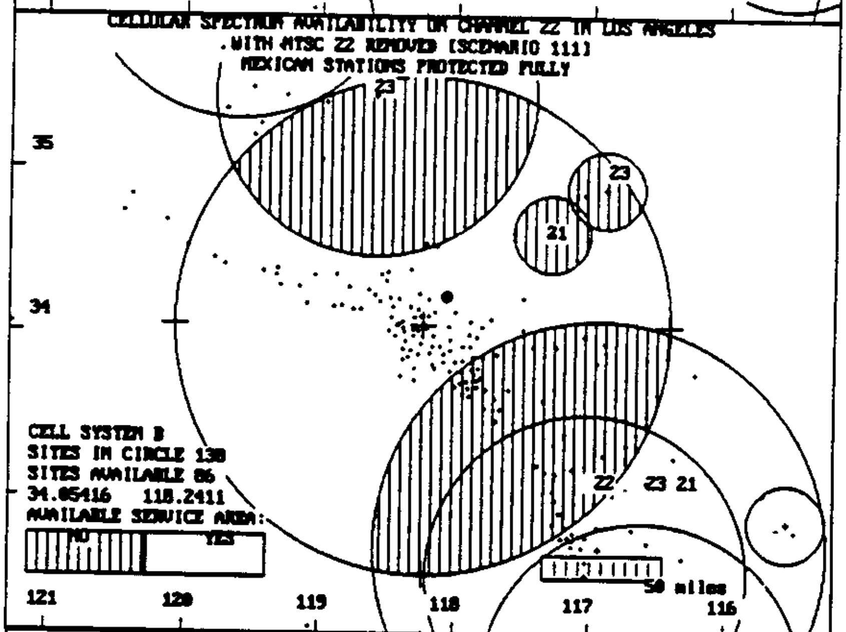

COMPOSITE CELLULAR SPECTRUM AVAILABILITY ON CHANNELS 67, 68 AND 69
IN LOS ANGELES WITH NTSC 68 REMOVED [SCENARIO 001]
MEXICAN STATIONS PROTECTED FULLY
67 69
69
35
66 68
66 68
67 69
67
68
34
69
67 67
66
67
69
67
66
CELL SYSTEM B
34.05416 118.2411
TV CHS. AVAILABLE
0
1
2
3
50 miles
121
120
119
118
117
116

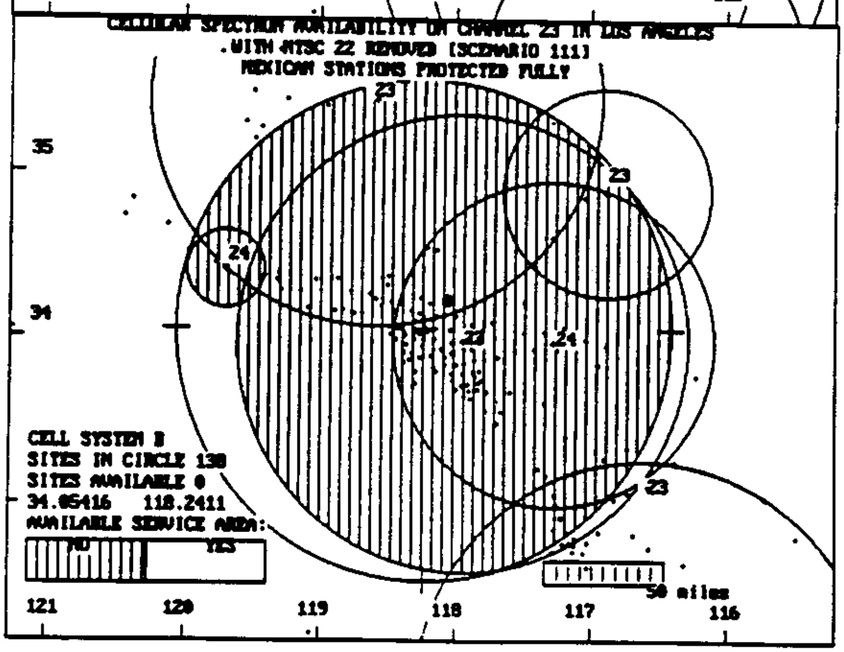

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 17 IN LOS ANGELES
.WITH NTSC 18 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
17
16
17
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 95
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116

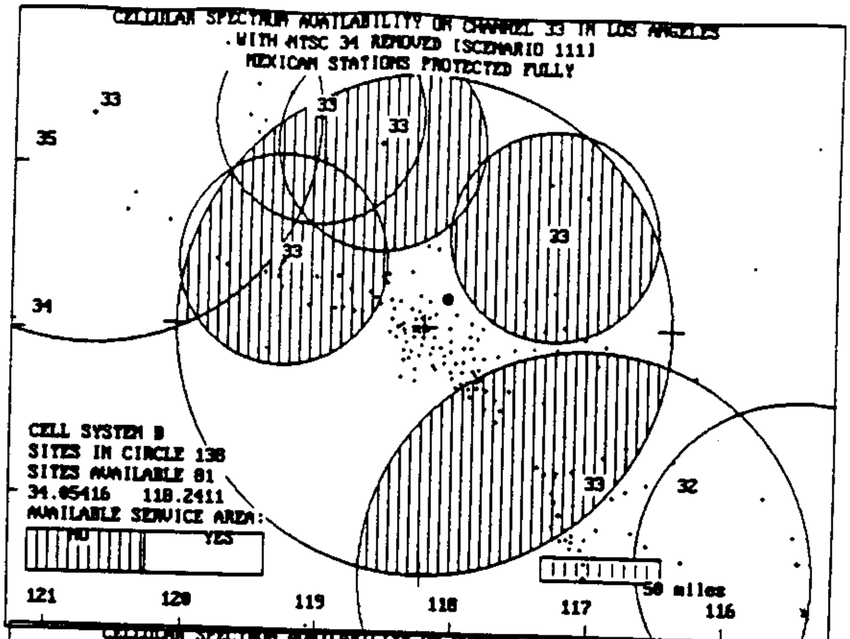

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 18 IN LOS ANGELES
.WITH NTSC 18 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
17
19
19
18
19
17
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 24
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116

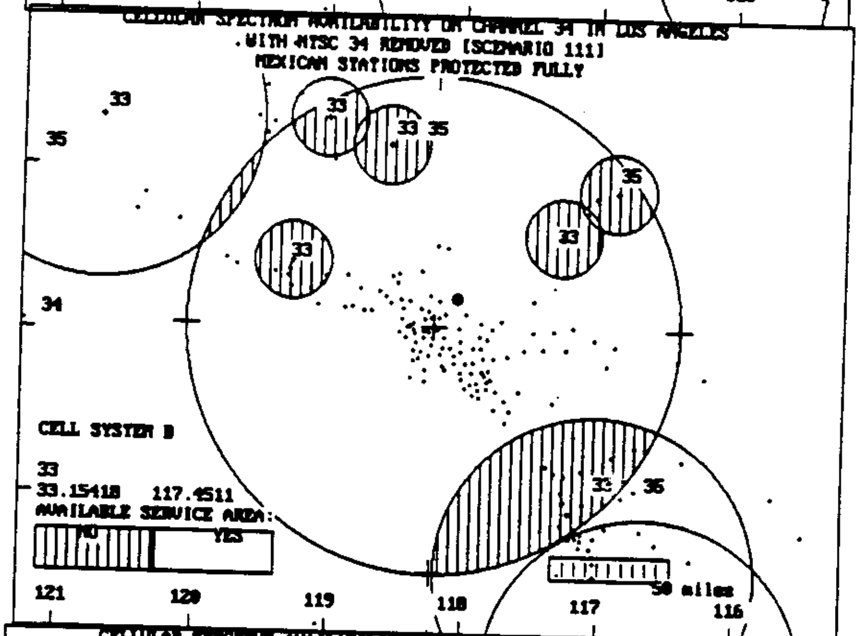

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 19 IN LOS ANGELES
.WITH NTSC 18 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
20
19
19
20
19
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 113
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116

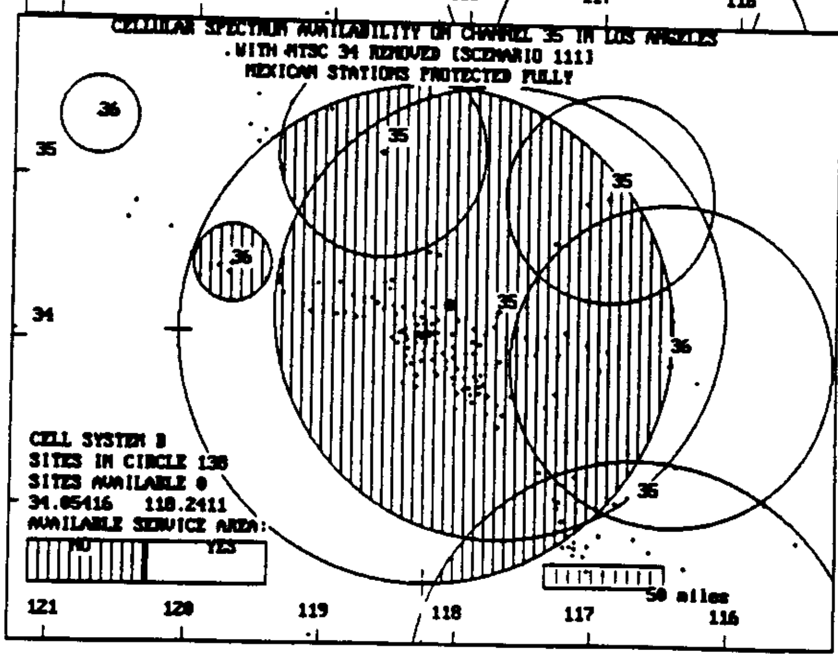

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 21 IN LOS ANGELES
WITH NTSC 22 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 99
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116

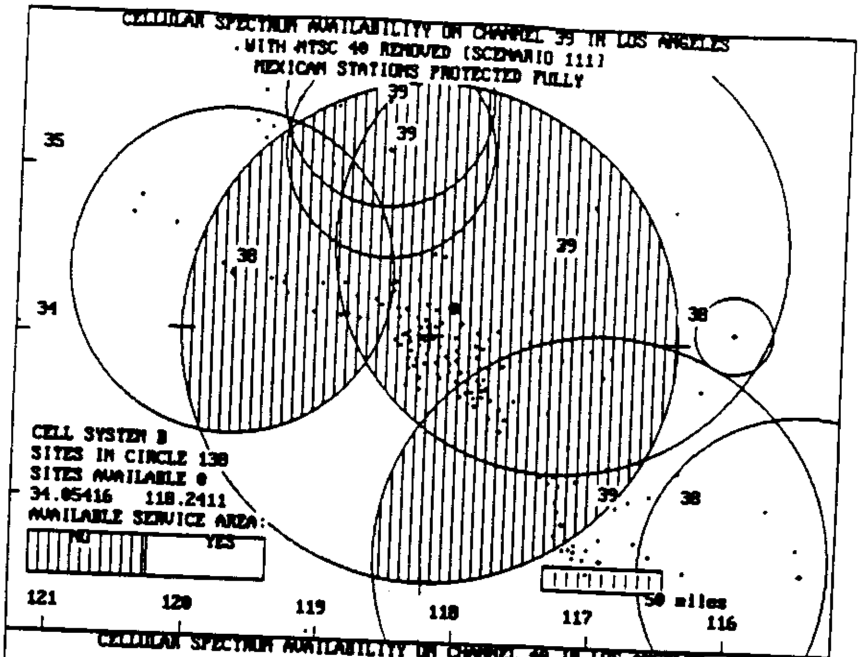

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 22 IN LOS ANGELES
WITH NTSC 22 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 86
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 23 IN LOS ANGELES
WITH NTSC 22 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 0
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 33 IN LOS ANGELES
WITH NTSC 34 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
33
35
34
32
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 81
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 34 IN LOS ANGELES
WITH NTSC 34 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
33
35
34
CELL SYSTEM B
33
33.15418 117.4511
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 35 IN LOS ANGELES
WITH NTSC 34 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
36
35
34
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 0
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 39 IN LOS ANGELES
WITH NTSC 40 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 0
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
35
34
121
120
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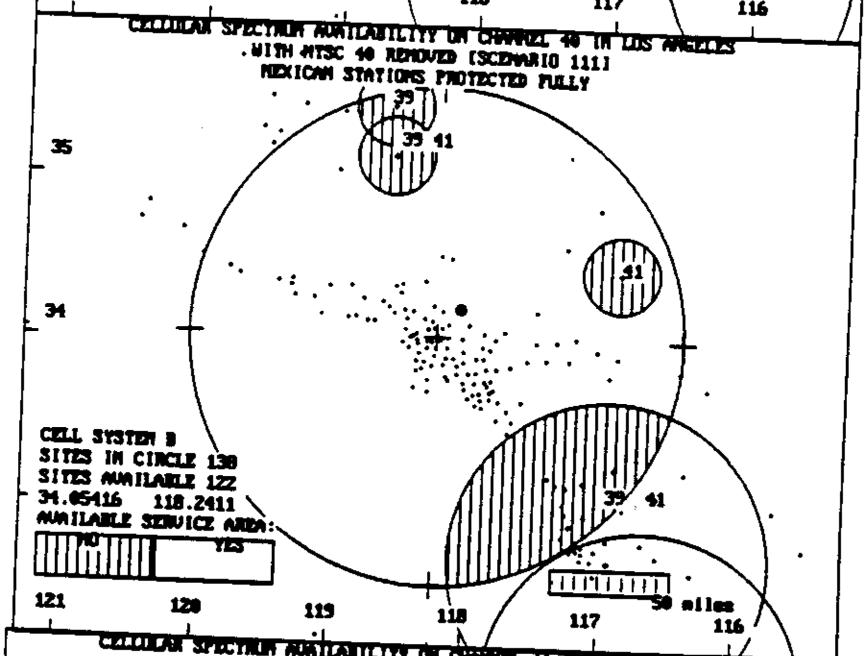
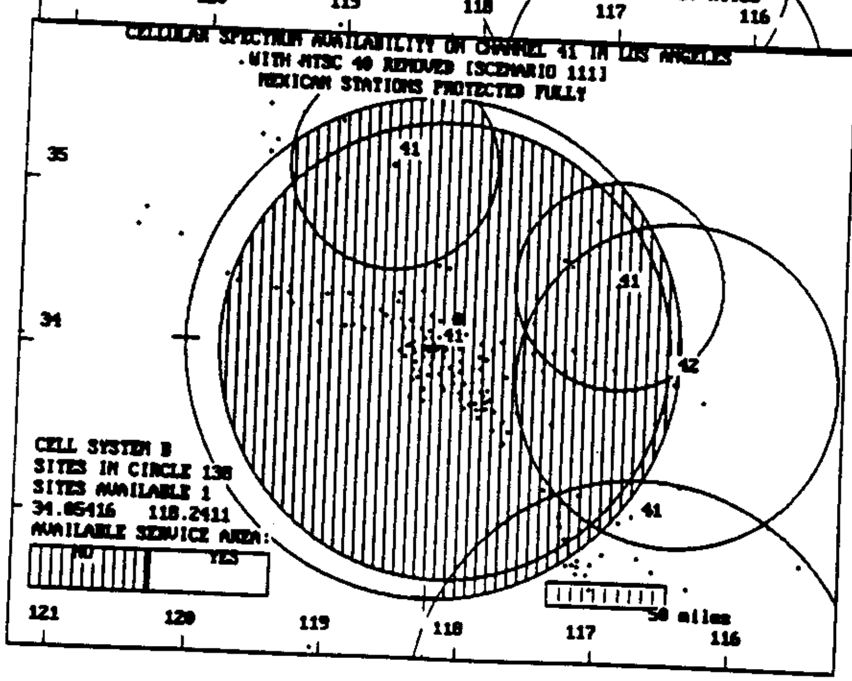
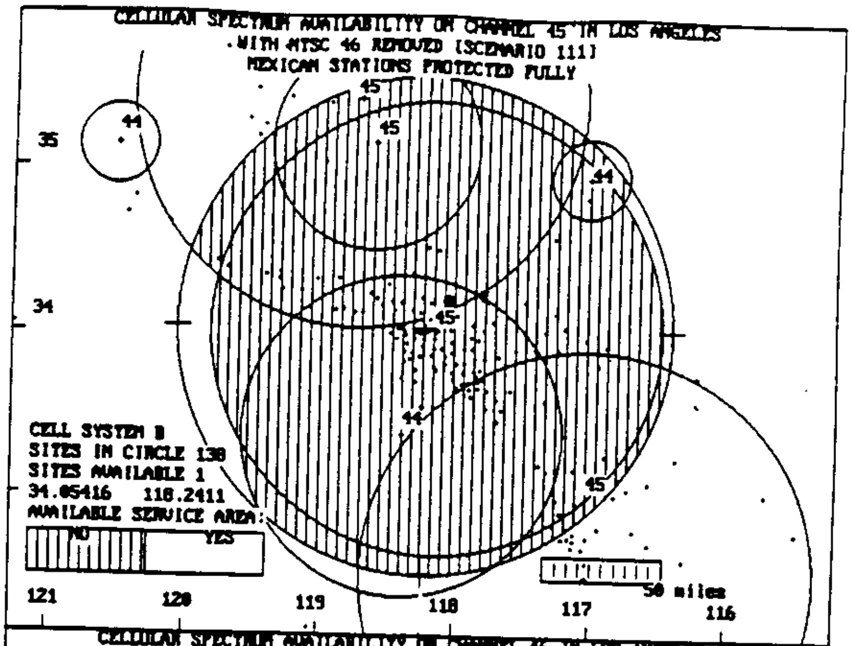
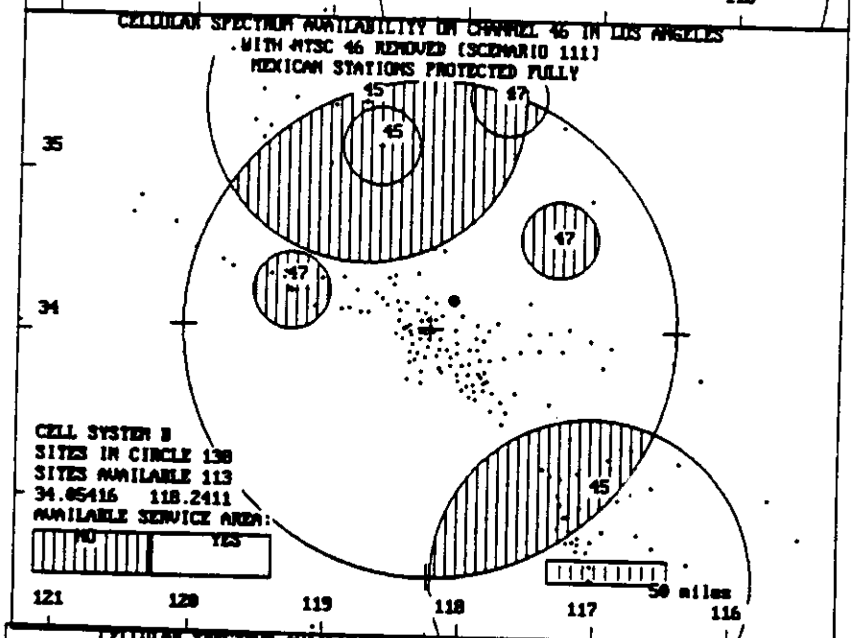
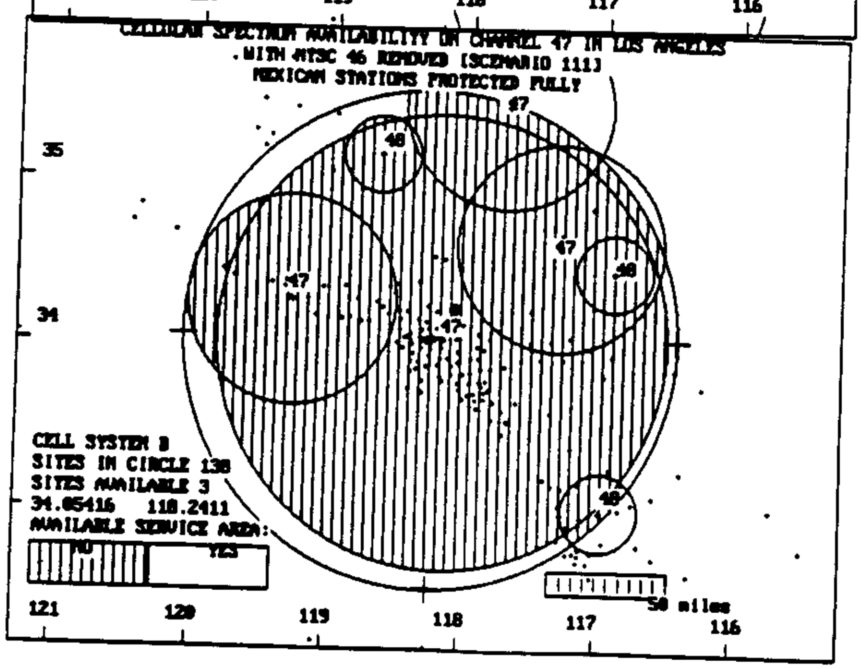
117
116

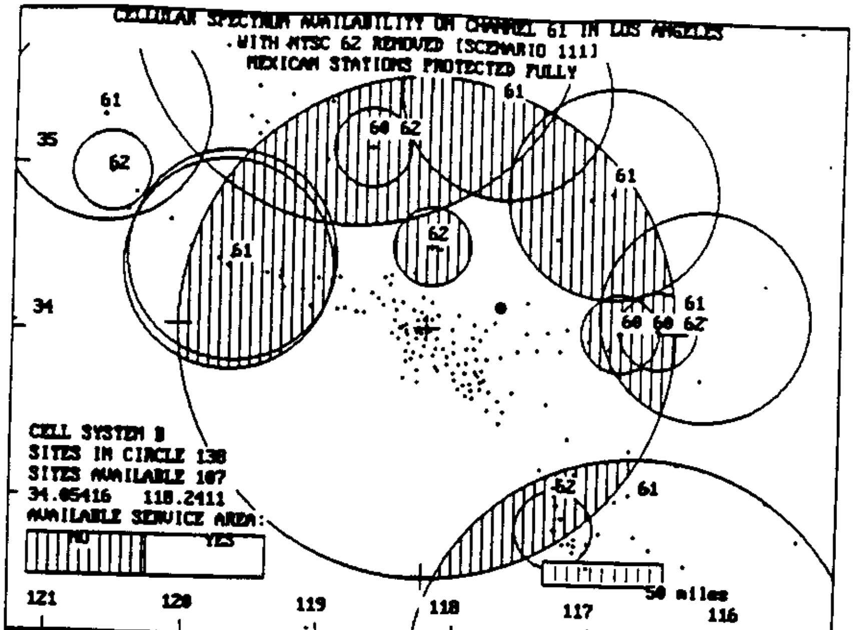

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 40 IN LOS ANGELES
WITH NTSC 40 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 122
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
35
34
121
120
119
118
117
116

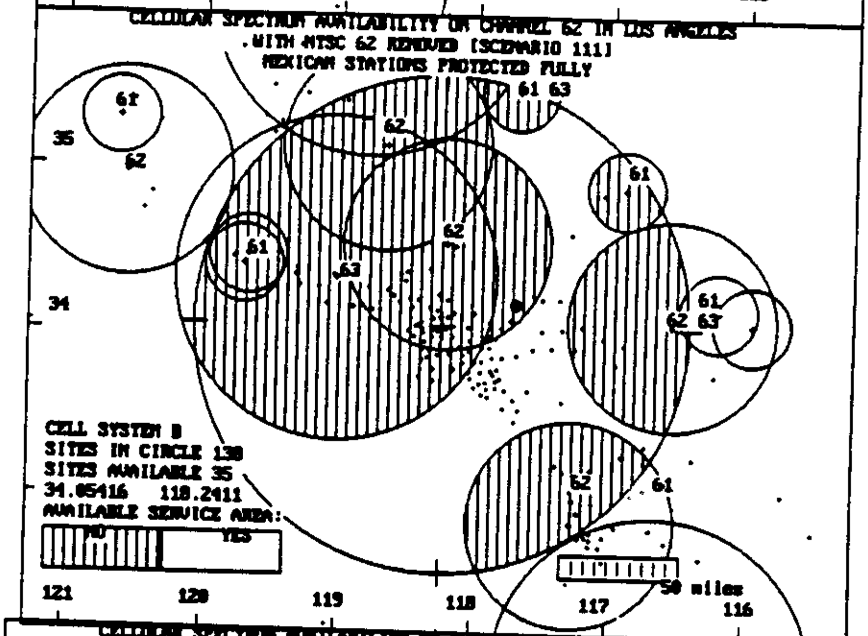

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 41 IN LOS ANGELES
WITH NTSC 40 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 1
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
35
34
121
120
119
118
117
116

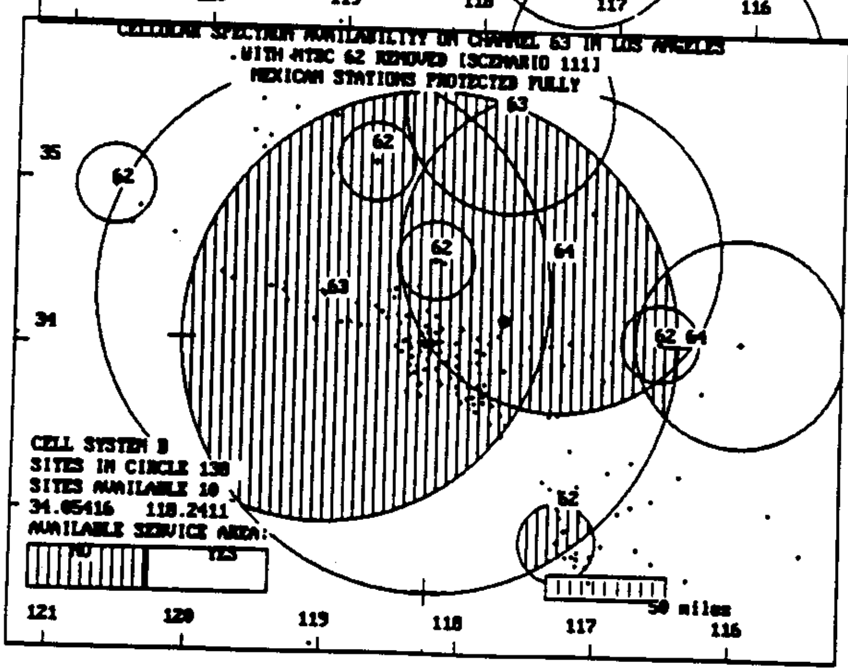

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 45 IN LOS ANGELES
WITH NTSC 46 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 1
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles

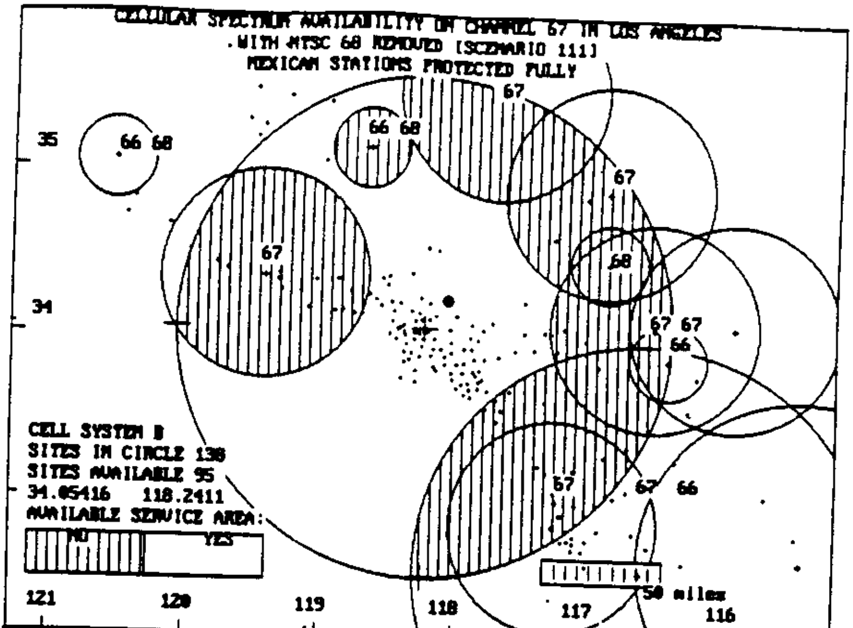

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 46 IN LOS ANGELES
WITH NTSC 46 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 113
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles

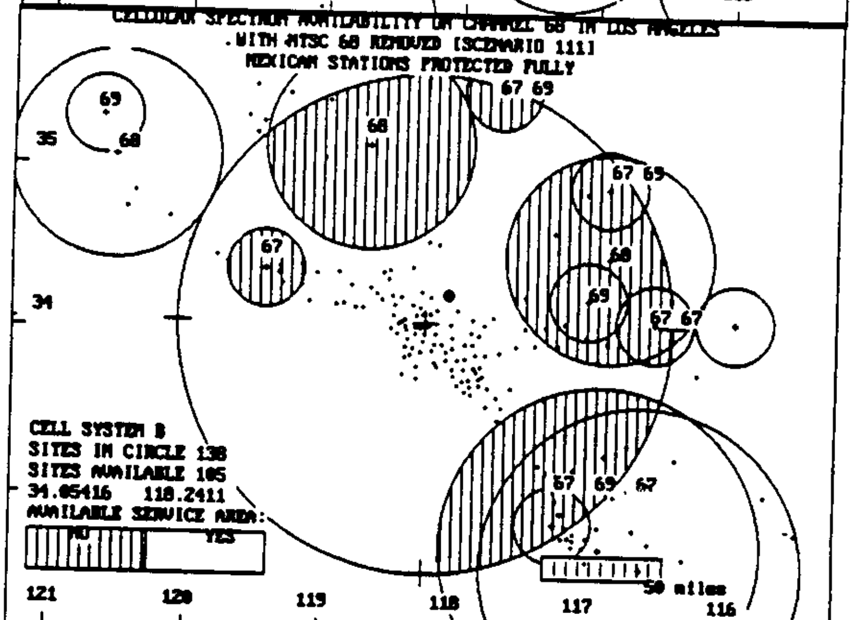

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 47 IN LOS ANGELES
WITH NTSC 46 REMOVED (SCENARIO 111)
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 3
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles

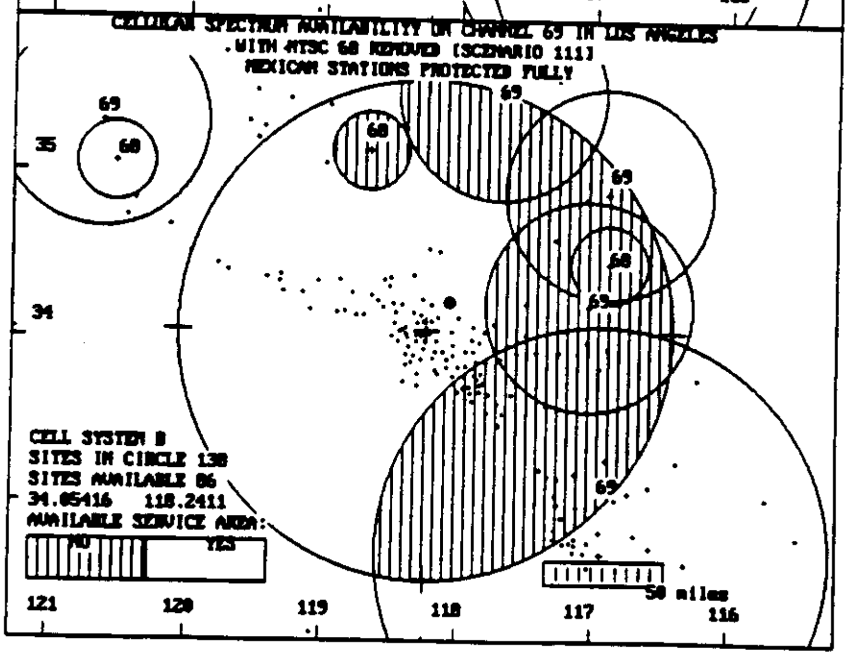

CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 61 IN LOS ANGELES
WITH NTSC 62 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 107
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
35
34
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 62 IN LOS ANGELES
WITH NTSC 62 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 35
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
35
34
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 63 IN LOS ANGELES
WITH NTSC 62 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 10
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles
35
34
121
120
119
118
117
116


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 67 IN LOS ANGELES
WITH NTSC 68 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 95
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 68 IN LOS ANGELES
WITH NTSC 68 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 105
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles


CELLULAR SPECTRUM AVAILABILITY ON CHANNEL 69 IN LOS ANGELES
WITH NTSC 68 REMOVED [SCENARIO 111]
MEXICAN STATIONS PROTECTED FULLY
CELL SYSTEM B
SITES IN CIRCLE 138
SITES AVAILABLE 86
34.05416 118.2411
AVAILABLE SERVICE AREA:
NO
YES
50 miles

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