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Optimization of High Throughput Grain Elevator Locations Using Decision Support Systems

by

Colleen Glen Yates

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

CALGARY, ALBERTA

JUNE, 1992

ISBN 0-315-79110-1

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Optimization of High Throughput Grain Elevator Locations Using Decision Support Systems" submitted by Colleen Glen Yates in partial fulfillment of the requirements for the degree of Master of Science.

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June 17, 1992

Abstract

The spatial organization of the western Canadian grain elevator system has evolved under changing agricultural and transportation conditions over the past century. The current trend is toward large, high throughput (htp) concrete facilities placed at a much wider spacing than the traditional wooden elevators.

The study addresses two related aspects of the elevator rationalization issue: the optimal province-wide spacing distance for htp elevators in Saskatchewan and the optimal location for one of these facilities in a htp-deficit study area. This type of optimization has traditionally been accomplished using the warehouse problem of linear programming, which considers only a single criterion, transportation costs. This study uses a more sophisticated approach, that of the Decision Support System which allows for the inclusion of many different and often conflicting criteria in the optimization process.

It is concluded that the optimal htp elevator spacing across the grain producing region of Saskatchewan is in the range of 40 to 60 kilometers apart. This spacing is a reflection of the current trend toward large scale, custom and commercial trucks for grain transportation from farm to elevator. The delivery point selected for the htp elevator site in the study area represents the best compromise between the interests of the six major players in the Canadian grain handling and transportation industry.

Acknowledgements

This thesis could not have been finished without the help and support of many people and organizations. First I wish to thank the Department of Geography for providing a T.A. position and summer support for my first year in the program. In addition, I am grateful to both the Province of Alberta and the Canadian Transportation Research Forum for scholarship support.

I owe a great deal to my supervisor, Dr. Nigel Waters for his inspiration, encouragement and support throughout the program. He always has time for me in his impossible schedule. Thank you also to Dale Schmeichel and Dr. Bob Bone who fostered my interest in Geography at the University of Saskatchewan and encouraged me to continue into a Master's program. Dr. Gordon Sparks has also been a great deal of help during the writing of my thesis. His guidance and willingness to help are greatly appreciated.

I would like to thank all of my friends and family for everything that they have done. I am especially glad to have met Kara and Brenda who have made the past two years a lot of fun. I am also grateful to my whole family for always encouraging me to do what I wanted to do and supporting my decisions. I would like to particularly thank my parents who, in addition to always being there for me, sent me every article and report on grain transportation they could find. Also my husband Tom, whose patience and encouragement were unfailing. Lastly, I want to thank Destiny for giving me a break from the rigors of University and time to clear my head.

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CHAPTER 1

INTRODUCTION

Grain elevator companies are currently rationalizing their western Canadian primary elevator operations. Primary elevators (or country elevators, as they were formerly known) are those to which producers deliver directly. They are the traditional elevators which mark the prairie landscape. Rationalization involves the introduction of new technically advanced facilities at some delivery points and the phasing out of elevator services at other points. Although this has been an ongoing process, with the number of elevators peaking in 1935 (Hall, 1977, p. 133), the rate of consolidation has accelerated in the past 15 years and is likely to continue doing so. The Saskatchewan Wheat Pool, for example, announced in 1990 that it is planning to halve the number of delivery points that it serves because 'the cost of maintenance and upgrading the system makes it almost prohibitive to keep these points open' (Saskatoon Star Phoenix, October 20, 1990).

Generally the decrease in the number of elevators was accompanied by an increase in storage capacity at the remaining sites (Zasada, 1968, p. 20). Historically this has been accomplished by either constructing additional, traditional elevators or by building annexes onto existing elevators. Recently however, the trend has been toward the introduction of large capacity inland grain terminals known as high throughput (htp) elevators. These are large concrete or steel structures which can handle much greater volumes of grain than the traditional wooden elevators due to their larger size and superior grain handling technical procedures.

The concept of inland terminals is not new. The first ones were built by the federal government between 1914 and 1917 in major prairie cities. The purpose of these facilities was to collect grain from country elevators and clean, inspect and stockpile it on the prairies in order to minimize bottlenecks at port terminals (Anderson, 1991, p. 15). The first htp facility of the modern type, the Weyburn Inland Terminal, was constructed in 1976 by a private group of grain producers. Soon after this the line elevator companies, beginning with Cargill, began constructing other inland terminals. The new facilities differ in function from the original ones. Not only are they more technologically complex, but they act as the primary collection facilities. The original inland terminals collected grain was from country elevators, they did not act as delivery points for producers. The new terminals, the htp elevators, replace country elevators as the facility to which producers deliver directly.

The change over to htp facilities appears to be a major step toward increasing efficiency in the grain handling and transportation industry as a whole. The Weyburn Inland Terminal has recently completed a study which concludes that increasing the efficiency of the grain handling system should be accomplished by increasing the number of htp elevators and decreasing the number of rail lines (Saskatoon Star Phoenix, January 29, 1991). Given that the consolidation of primary elevators is the current trend in the grain industry, the major issue becomes how to optimize the rationalization process.

1.1. Problem Statement and Research Objectives

This thesis will address two related aspects of the grain elevator rationalization issue. The first of these is to determine the optimal distribution or spacing of htp facilities on a province-wide basis for the province of Saskatchewan. The second, is to determine the optimal location for a terminal in a study area which, based on the pre-determined optimal spacing, is not currently serviced by an htp elevator. Subsidiary to this will be the determination of whether or not a portion of the railway branch line in the case study area should be abandoned. If the delivery point selected as an htp site is not located at the terminus of a branch line, the need for rail service from the htp delivery point to the end of the line is negated.

From a technical standpoint, the thesis will also compare the optimal solution determined by a single variable, deterministic method (namely that of the warehouse problem of linear programming) with solutions obtained from multi-criteria Decision Support Systems (DSS).

Based on the above objectives, the following hypotheses will be tested.

1. The existing configuration of primary elevators is not optimal. The efficiency of the system can be improved while also serving the interests of all players.
2. The use of DSS will produce more realistic, balanced results than a single variable mathematical programming model.

1.2. Theoretical Framework

The elevator location problem involves locating a set of facilities and is essentially an extension of the industrial location theory first put forth by Weber (1929). Weberian theory states that facilities will be located where total transportation costs are minimized. As with the multiple-criteria, decision making approach used by DSS, Weberian Theory acknowledges that criteria other than transportation costs are important in the location decision process. Weberian Theory does not incorporate these other costs directly, rather, they are converted to transportation costs. DSS on the other hand treat each criterion or factor as an individual entity, they are not converted to a standard measure.

The problem also draws on Central Place Theory, first developed in the 1930s by Christaller (1966). Although Central Place Theory is used to explain the location and spacing of service centers, not specific facilities, it is an important underpinning to the empirical search for the optimal elevator spacing. In a prairie context a grain elevator can be considered a central place service. As such the problem becomes one of determining the appropriate spacing for the service based on its range and threshold.

1.3. Thesis Structure

Chapter two of the thesis reviews the historical background to the elevator consolidation issue. This complex issue can only be fully understood when placed in the appropriate context. The history of the two major aspects of the grain handling and transportation system, the elevators and railways, as well as the role of the grain industry in national and regional development are all reviewed.

The third chapter provides a literature review of work in three main subject areas. The first is prairie grain elevator consolidation. The second is location/allocation modelling with particular reference to the modelling of the transportation and warehousing of agricultural products. The final section deals with DSS and the use of DSS in location problems.

The fourth chapter outlines the methodology used to resolve the study problem. It is divided into two parts. The first deals with the macro-level spacing study and the second, with the micro-level case study.

Results and analysis are covered in the fifth chapter. Once again the macro and micro level areas are dealt with individually. In addition to the results of the analysis, a critical review of the DSS software packages used is included. The final chapter includes a thesis summary and conclusions.

1.4. Summary

The thesis will determine an optimal spatial arrangement for htp terminals for the grain producing area of the province of Saskatchewan. Based on this optimal spacing a study area which is lacking an htp elevator will be identified. Using both the warehouse problem of linear programming and DSS, the specific location for an htp facility within this study area will be identified.

The study area analysis will first be performed using the warehouse problem of linear programming, which uses transportation costs as the sole decision criterion. This solution will then be compared with those reached using four different decision support systems, which allow for the use of many other criteria. Once an optimal solution is determined regarding the location of delivery points, it may also suggest system savings through the abandonment of a segment of a grain-dependent prairie branch line which becomes redundant.

CHAPTER 2

HISTORICAL BACKGROUND

2.1. Introduction

In order to understand fully the current grain handling and transportation system, it must be placed in its historical context. This section will very briefly outline the development of the Western Canadian grain handling and transportation system and changes in the system over time. Points covered will include the role of western Canadian agriculture in national development, the railways, elevators and social issues.

2.2. Western Canadian Agriculture and National Development

Grain production in Western Canada has been an integral part of the Canadian nation since Confederation. When the dominion was established in 1867, the federal government adopted a development plan known as the National Policy (Fowke, 1957). This essentially had the effect of concentrating manufacturing interests in Central Canada and creating a primary industry base, particularly grain production, for Western Canada. The settling of the prairies, predominantly at the end of the 19th and beginning of the 20th centuries, fulfilled two of the major goals of the National Policy. First, a market was created for Central Canadian manufactured goods and second, food for both domestic consumption and foreign trade was produced. The tie that bound the two regions was the railway (Fowke, 1957).

2.3. The Railways

In the late 19th and early 20th centuries the railway was the only viable method for the overland transport of bulk goods. Most of the prairie rail network was constructed during this period however it suffered because, from an economic perspective, it was overbuilt. Numerous competing railway companies engaged in a building frenzy in the early years of the twentieth century. The overly competitive nature of the railway industry led to the bankruptcy of many of the companies. The assets of these bankrupt companies were consolidated by the federal government into the Canadian National Railway in 1919. The Canadian National not only inherited a system with duplicate lines but also had to compete with the Canadian Pacific in areas where the market size could not support two railways (Hall, 1977, pp. 26-30).

In addition to having an overbuilt network, the railways felt that they could not invest heavily in the repair or maintenance of deteriorating branch lines due to revenue restrictions imposed by statutory freight rates. Until its abolition in 1982, all grain was shipped under the 1897 statutory Crowsnest Pass Agreement which froze rates for "eternity". Over time, the railways' costs increased with no corresponding increase in the revenue generated by grain dependent prairie branch lines. The federal government did provide some assistance however many lines operated at a loss. As such, railway companies were reluctant to allocate maintenance resources to these unprofitable lines (Hall, 1977, p. 19).

For the financial reasons stated previously, the railways began to abandon some of the least profitable prairie branch lines. These were usually low volume, grain dependent lines i.e. those which carried almost exclusively grain and had a low density of traffic. This abandonment occurred in three major phases: the early 1960s, 1975, and from mid-1977 to 1983 (Grain Transportation Agency, Transport Canada and Agriculture Canada, 1991, p. 6). The Royal Commission on Grain Handling and Transportation, or Hall Commission, which reported in 1977 had a great impact on branch line abandonment. The Commission's recommendations regarding the fate of every prairie branch line were essentially put into law by the federal government. Most of those considered suitable for abandonment by Hall were removed from the network in the late 1970s. Since this time the network has been relatively stable. This may change again after the year 2000 however when government protection ends.

2.4. Grain Elevators

The first delivery point facilities, built in the final decades of the nineteenth century, consisted of flat warehouses which could handle only bagged grain. From the turn of the century onward however, wooden country elevators dominated and by 1920 flat warehouses were completely out of use (Anderson, p. 14, 1991). Elevators handle bulk grain deliveries and could thus put through substantially larger quantities of grain, as well as mix grades, making them far more efficient for loading railway cars.

The first prairie grain elevator was built at Gretna, Manitoba in 1881. After this so-called "line elevator companies" built a system of country elevators on rail lines throughout the prairies. The line elevator companies were operated by both private companies and later, cooperative producer groups.

The number of elevators rose steadily, peaking in 1935 (Hall, 1977, p. 48). Since that time, the number of elevators has been decreasing but, until the 1970s elevator capacity increased. This was due to several factors. Most importantly old, small elevators were replaced by larger ones and others had storage annexes added to them. Since htp elevators have been introduced however, grain elevator storage capacity on the prairies has actually dropped for the first time in history. In the 1970-71 crop year western Canadian grain elevator capacity was 398,888 bushels. By the 1980-81 crop year htp facilities had begun to appear on the prairies and capacity decreased to 312,451 bushels (Anderson, 1991, p. 14). By the 1989-90 crop year, capacity had dropped to 251099.48 bushels (Canadian Grain Commission, Economics and Statistics Division, 1989-90 "Grain Deliveries at Prairie Points, Crop Year" Reports).

When the prairie grain collection system was established, grain transportation from farm to delivery point was accomplished using horse and wagon. This necessitated a dense network of delivery points so that round trip deliveries could be made in one day. The elevator system which was created, based on horse transportation had delivery points approximately 6-10 miles apart, located along railway lines (Wilson and Tyrchnwiewicz, 1980, p. 1). Subsequent branch line abandonment caused the closure of many primary elevators located at delivery points along the abandoned lines. The elevators were required to close not only because they were no longer serviced by rail but also because, under most current agreements, an elevator must be on a rail line in order to be licensed. The on-line licence condition has been relaxed in a few circumstances in order to retain grain storage space and allow producers to remain a reasonable distance from a delivery point. Grain is shipped by large truck from these off-line points to an on-line elevator.

In the 1970s, a new factor, the inland grain terminal, came on the grain elevator scene. These large facilities offered economies of scale, therefore lower per unit elevation charges for producers as well as a large capacity, high volume train loading capacity which benefitted the railway.

As an alternative to using the elevator system, producers have the right to order and load their own grain cars. This practice is most common when grain prices are low, as it eliminates the expense of elevation charges. In 1981 for example, when grain prices were relatively strong, 2954 out of 402,109 or 0.7% of rail cars shipped to port were producer cars (Canadian Grain Commission, 1981). In 1991, when grain prices were extremely depressed, 11,637 out of a total of 370,606 or 3.1% cars were producer cars (Canadian Grain Commission, 1991). The practice is of relatively little importance in terms of total grain shipped however and as such, has little effect on elevator location decisions.

2.5. Social Issues

Branch line rationalization and elevator consolidation are both strong emotional and political, as well as economic issues. It has been popularly held that once a town loses its rail line and/or grain elevators, it will cease to function. This belief led to strong, emotional protests in the 1970s when the rate of rail line abandonment was greatly accelerating (Wilson, 1981).

In a study for The Grains Group (1972) and subsequent work (1973, 1987), Stabler has argued that branch line and elevator abandonment is not related to town sustainability however. He argues that the retention or abandonment of these facilities had little effect on the decline or prosperity of towns. While acknowledging that commercial function and relative location are important variables in explaining the relative growth or decline of a community, other factors also play a role (Stabler, 1987). He proposes that the growth of a town is dependent partially on its location as well as the commercial and non-commercial (institutional) functions such as schools and hospitals that it offers. Grain elevators were not seen as vital to viability. Between 1961 and 1971 twenty-one centres lost elevators. While eleven of them declined in terms of commercial level, five were unchanged and five grew. Five also experienced population growth. For the province as a whole, communities which lost elevators and those which retained them exhibited similar growth patterns (Stabler, 1987).

2.6. Summary

Four factors are particularly important to understanding the historical context of the current grain elevator rationalization issue and the interests of the major players involved. These areas are: agriculture and its role in economic development, the railways, the development of the prairie elevator network and communities and social concerns. The more fully these issues are understood, the better the points of view of the concerned players can be understood and treated sympathetically in the criteria selection and objective trade-off process. In this way the most truly satisficing location can be chosen.

Through the instrument of the National Policy, the prairies were established as a grain production region by the first Canadian Government. This has been reinforced over time by investment and population patterns. Due to the early producers' reliance on horse and wagon to deliver grain, collection points were established relatively close together. As such a dense network of rail lines and primary elevators was created. Two factors prompted action to consolidate and rationalize these dense networks. First, as transportation efficiency increased, it became practical for producers to haul farther distances. Second, due to fierce competition the railways initially overbuilt their systems and thus later felt it necessary to consolidate for economic reasons.

Elevator companies have also been consolidating their system since the mid-1930s in response to economic forces. Originally this took the form of phasing out small elevators and either adding annexes to existing facilities or constructing new, larger traditional ones. Beginning in 1976 with the Weyburn Terminal, a radical new approach has been introduced. This involves the construction of extremely large concrete or steel high throughput elevators placed at a considerably greater spacing than the traditional elevators.

The overall issue of grain handling and transportation system rationalization has had strong social and political overtones. Questions have been raised as to the motives of some of the players involved. Producers and rural communities have been and are particularly concerned that the removal of the rail line and/or elevators from a community will lead to its demise. It has been argued however that many other factors are more important in determining a community's viability and that often elevator removal is a symptom rather than a cause of rural decline.

CHAPTER 3

LITERATURE REVIEW

3.1. Introduction

The following literature review provides a background to relevant previous work on three major subjects related to the current thesis. This includes both theoretical approaches and practical applications. The first of these is the rationalization of the grain handling and transportation system. In particular the focus is on the consolidation of the railway and grain elevator networks. The second is mathematical modelling of location problems, including the traditional approach of location/allocation modelling. The final focuses on DSS. This includes the development of the DSS field as well as applications of DSS to location problems.

3.2. Rationalization of the Primary Elevator System

In the late 1960s and early 1970s it was realized that changing economic and technical factors would require a major change in the nature of the Canadian grain handling and transportation system. This resulted in numerous studies on current industry conditions, proposed changes in it and then predicted results of these changes.

In the early 1970s the Canada Grains Council prepared a comprehensive report outlining the current state of the industry. The focus of the study was threefold. First it described the current grain handling and transportation system and outlined its historic development. Second, it recommended modifications which would increase the system's capability and third, it made recommendations for the long term development of the system. These recommendations included a reconsideration of existing grain handling and transportation tariffs, i.e. the Crow Rate, as it was seen to discourage increased system efficiency (Canada Grains Council, 1973, p. 185). The study also notes that grain elevator consolidation goals are not necessarily consistent with branch line abandonment since the two groups, namely the railway and elevator companies, have rarely targeted the same locations (p.170). In addition, the study notes that the high capital investment for new primary elevators can rarely be justified (p. 142). Three points regarding producer attitudes are discussed which work against the development of a consolidated elevator network. First, producers do not want to see their own delivery point closed from a "right to service" point of view. This may be especially important if the elevator is part of a producer owned pool or coop. Second, trucking costs increase, although this may be negated if a more distant delivery point which benefits from consolidation can offer lower handling tariffs. Third, due to a maximum handling cost limit, handling costs do not necessarily reflect true user costs, thus producers may not realize the true cost of operating a non-competitive point (pp. 152-3). In addition to the Canadian Grain Commission's work, Kulshreshtha (1975) provides a summary of many of the earlier studies, which were primarily concerned with identifying major unresolved issues.

The 1977 Royal Commission on Grain Handling and Transportation, or Hall Commission, included a prairie wide examination of the primary elevator system. The study approached the issue of primary elevator rationalization indirectly. The commission's primary mandate was to make recommendations as to the future of the deteriorating prairie branch line network. As such, recommendations regarding the abandonment or retention of branch lines determined the fate of the primary elevators located along them. This is because generally, as noted previously, an elevator must be on a rail line in order to be licensed.

Although the commission dealt with the entire prairie branch line system, abandonment decisions were essentially piecemeal. The lines were examined as individual entities, not necessarily as they fit into the overall network. Decisions were made on the basis of criteria such as tons of grain shipped on the line and branch line maintenance costs, producer hauling distance to alternate delivery points was not always considered. The commission recommended lines be either abandoned, administered by a special crown corporation, or added to a basic network and protected until the year 2000.

Following on the work of the Hall Commission, Wilson and Tyrchniewicz reviewed the role of transportation in the development of western Canadian agriculture. They concluded that there is a definite trend toward elevator consolidation, driven by economic forces which increase the capacity for which each elevator manager is responsible. Other influences on consolidation are rail line abandonment and improvements in the rural road network (1980, p. 40).

While the previously mentioned works provide relevant material, the information must be interpreted with caution since the studies were completed before the abolition of the Crow Rate in 1982. Since the Crow Rate has been removed, rail rates for grain transport are no longer limited by statute. This change in rate structure may cause changes in optimal elevator locations. Among other things, producers are responsible for an increasing proportion of the cost of shipping grain because the government's share rather that the producers' share is now a fixed amount. This may decrease the number of producers growing and shipping export grain.

Both the Hall Commission (1977) and Wilson (1981) discuss the historical background to the current grain handling and transportation system and summarize the main issues surrounding rationalization. In addition, Chaudhary (1987b) provides a more recent summary of the current issues in the grain handling industry. He discusses the consolidation of the prairie primary elevator system and the subsequent increased use of htp elevators and inland terminals. Anderson (1991) outlines the historical development of the private grain elevator companies and discusses the trend toward consolidation and the use of htp elevators.

Meyer and Sparks (1987) discuss the economic implications of the trade off between the current grain collection system, with numerous delivery points and relatively short hauling distances and a rationalized system with fewer points and longer haul distances. They conclude that economies of scale and other efficiency measures associated with a rationalized system decrease the marginal and average costs sufficiently to offset the effects of increased hauling distance.

Meyer and Sparks also outline the interests and perspectives of the major players in the primary elevator rationalization issue. This is important since rationalization, while possibly reducing the total system costs can increase the specific costs accruing to one or more of the players. In brief, the interests of each of the major players is as follows. Grain producers are primarily concerned with the additional costs which may be associated with hauling further distances if certain delivery points are abandoned. As well, they may face higher taxes due to the higher maintenance costs incurred by increased traffic levels on municipal roads. Grain companies face high short term costs if revamping the grain collection system involves the construction of new facilities. Short run costs are also affected by settling labour issues with managers, whose numbers would have to be reduced. On the other hand, grain companies stand to benefit from long run savings by operating fewer, more efficient facilities. The major concern of municipal governments is the additional wear on the roads caused by increased trucking of grain. This is also a concern of the provincial government, which is responsible for the highway network. These additional costs will not be accompanied by additional revenues. The federal government's primary concern is moving grain, an important foreign exchange earner, to tidewater as economically as possible in order to increase the competitiveness of Canadian grain on the world market.

Meyer and Schoney (1990) argue that the following cost savings could be realized in a rationalized grain handling and transportation system with fewer delivery points and an increased use of trucking. First, it would help facilitate the loading of unit trains, decreasing turn-around time, thereby reducing per unit rail transportation costs. Second, it would allow for the closing of some grain dependent branch lines, thus reducing costs for the rail companies. Meyer and Schoney do point out however that trucking distance and therefore transportation costs will increase. This may however be off-set by the use of more efficient methods of trucking, thereby reducing per unit costs, particularly since many costs associated with trucking are fixed.

In addition to the aforementioned literature, several government agencies have undertaken relevant studies. The Canadian Transport Commission has produced several reports on primary elevator consolidation. Two of these have particular reference to the current study in that they both examine the economic effects of rationalizing the grain handling and transportation system. Flemming and Yansouni (1978) evaluated the effects of rail line abandonment on the grain handling and transportation system as a whole in the wake of the Hall commission's recommendations. They conclude that, if the lines which Hall recommended for abandonment were abandoned and some of the other lines whose futures were questionable (in 1978) were also abandoned that there was a potential for system savings. Their calculation included the cost of upgrading elevators at the remaining delivery points but excluded road cost increases. Gemmel (1986) concluded that elevator consolidation would increase trucking costs, reduce elevator costs and might decrease rail costs. He notes that although farmers will likely have to incur the additional trucking costs, elevator savings will benefit producer owned elevator cooperatives.

A newly released study prepared for the Senior Grain Transportation Committee (1991) examines the savings which could be realized by closing a number of low density, grain dependent branch lines and trucking grain to alternative delivery points on other lines. In addition, it examined the option of off-track elevators, i.e., permitting the licensing of elevators which are not on rail lines to be used as bases for grain trucking to a rail delivery point. The study concludes that considerable savings, in the order of 18 million dollars, could be realized by closing 34 branch line sections, totalling 1366 miles. This represents approximately one fifth of all grain dependent prairie branch lines. The increase in system efficiency and cost reduction due to the increased rationalization of grain dependent branch lines was also supported by a group consisting of the Grain Transportation Agency, Transport Canada and Agriculture Canada in a discussion Paper released in January of 1991.

In March of 1991 the Saskatchewan Government released a discussion paper in response to the above mentioned Senior Grain Transportation Committee study (Saskatchewan Highways and Transportation, 1991). They strongly opposed many of the ideas put forth in the federal paper. In particular, they take exception to the idea that branch line abandonment should continue. There are two main reasons for this opposition. First, it would cause delivery point closures, thus creating longer hauling distances and therefore, increased variable costs for producers. Second, it would create a greater need for grain to be trucked. The increase in trucking would increase wear and tear on the road network, which is a provincial not a federal responsibility. The Saskatchewan government is anxious to point out that some of the so called "cost saving measures" involved with rationalization are not truly savings, but rather transfers of responsibilities without a corresponding increase in revenue, from the federal to the provincial government and that this is one of the reasons rationalization has been encouraged by Ottawa. In addition, it cautions that while rationalization may result in over all system savings it will definitely increase costs in certain specific areas, thus some players will be asked to bear the brunt.

The Saskatchewan Government study also points out alternatives for grain collection in the event of branch line abandonment. These include short line railways and off-line elevators.

The most recent study on the issue is the "Transportation Talks" report produced by Peat Marwick Stevenson and Kellogg for Agriculture Canada (1992). The report is a summary of a series of workshops held with producers across Canada in January and February of 1992. There were two main points raised which are of interest to the current study. First, producers agreed in principal to system rationalization, provided that they benefit through decreased per unit costs and improved service. There was a concern that producers directly affected by abandonment receive some form of compensation however (p. 5). The second point is that no producer should have to truck more than 25 to 30 miles (p. 14).

3.3. General Transportation and Location/Allocation Modelling

Love, Morris and Wesolowsky (1988, pp. 7-9) outline the historic approaches to location problems. They trace the formal study of location problems to Torricelli in 1640 and Fermat in the 17th century. Fermat's essay explored methods for locating a minimum distance point. Location allocation studies did not truly come to the fore however until the rapid post-war development of the operations research field. At this point rigorous mathematical concepts and procedures were applied to problems. This approach was greatly stimulated by Ford and Fulkerson's (1962) book Flows in Networks.

The following work provides an overview and summary of the transportation geography location-allocation field. Taaffe and Gauthier (1973) discuss the major foci of the discipline of transportation geography. They include such topics as types of transportation networks, commodity flow, hinterlands, quantitative methods in transportation geography and allocation models. Abler, Adams and Gould (1971) also provide an overall summary of spatial concepts which includes a review of geography's perspective on location/allocation and transportation in general. Ghosh and Rushton (1987) focus on spatial analysis using location-allocation models.

3.4. Mathematical Programming Approaches

The problem of elevator rationalization may be formulated as the classical warehouse problem (a transportation problem with transhipment points) of linear programming. In the warehouse problem, which is an extension of the transportation problem developed by Orden (1956), a set of intermediate storage points (j) are required for a product which is produced at another set of points (i) for which demand occurs at a third set of points (k). In the grain transportation problem, the locations of i, the farms, and k, the port terminals are known and fixed. The problem becomes one of determining the optimal locations for j, the primary elevators. The algorithm can be written as follows (Killen, 1983, p. 66):

Minimize: $$\sum_{i=1}^{m} \sum_{j=1}^{q} c_{ij} \quad x_{ij} + \sum_{j=1}^{q} \sum_{k=1}^{n} c_{jk} \quad x_{jk}$$

s.t. $$\sum_{j=1}^{q} x_{ij} = s_i;\ 1, \ldots, m$$

$$\sum_{j=1}^{n} x_{jk} = d_k;\ 1, \ldots, n$$

$$\sum_{i=1}^{m} x_{ij} - \sum_{k=1}^{n} x_{jk} = 0;\ j=1,\ldots, q$$

Where:
c_{ij} = cost of transporting one unit from i to j
c_{jk} = cost of transporting one unit from j to k
x_{ij} = number of units transported from i to j
x_{jk} = number of units transported from j to k
s_i = quantity supplied at i
d_k = quantity demanded at k

There exists a large literature regarding algorithms and methods for solving the transportation problem both with and without transhipment points. Summaries of these are included in Killen (1983) and Frazer (1968). The algorithms can be divided into two main categories, those dealing with continuous space and those dealing with discrete space. Continuous space problems are those in which the selected location can occur anywhere within the study area. An example of a continuous space algorithm is the omega-method P-median developed by Khumalwala (in Killen, 1983, p. 230). In discrete space problems however, the selected location can only occur at one or more pre-determined nodes. An example of a discrete space problem is Orden's Warehouse problem (1956), in which the chosen location can only occur at one or more predetermined nodes (j). The current htp elevator location study occurs in discrete space.

Goodchild and Noronha (1983) produced a monograph and computer source code package for solving location-allocation problems. This system contains several shortest path algorithms. The output from these is used as input for the actual location-allocation algorithm ALLOC. They discuss using the technique of Hillsman editing (Hillsman, 1984) to modify a set of weighted distances in order to solve problems with different objectives.

Many studies which deal with the warehouse problem have made use of public domain or commercial software packages. Wirasinghe and Waters (1983) used Lea's (1973) WARELOC program in locating solid-waste transfer sites. WARELOC is a public domain software package for solving the warehouse problem. Wirasinghe and

Waters' (1983) problem involved selecting one or more garbage transfer stations (i.e. warehouses or transhipment points) which were to be located between the households generating the refuse and the landfill site. The main contribution of this paper is that it allowed the size, and therefore the cost of the facility to vary. Glen and Bone (1989) used Eastern Software's (1984) TSA88, a linear programming transportation transhipment program, to determine the optimal distribution pattern for fluid milk delivery to remote northern communities. The study uses transhipment points as break-of-bulk points, rather than collection points.

There is a rich literature on the application of linear programming techniques to network problems (Handler and Mirchandani, 1979; Love, Morris and Wesolowsky, 1988; Smith, 1982; Rockafellar, 1984; Killen 1983). Handler and Michandani (1979) outline different approaches which can be taken to facility location. In particular they discuss single vs. multiple facility location, as well as deterministic vs. probabilistic networks. Deterministic networks are those in which demand levels and demand locations are known and constant rather than random. They also discuss various exact and heuristic computational methods.

Backhouse (1973) uses the transportation problem, without transhipment points, in a specifically agricultural context to study the changes in elevator service areas, or hinterlands, resulting from branch line abandonment. The problem is structured with farms as supply points and elevators as demand nodes. The study does not consider the movement from elevator to port. The objective function was to minimize total transportation costs while maintaining a complete transfer of grain from farms to elevators. In this study supply and demand figures are the ten year average of receipts at primary elevators in the study area. A ten year average is used to decrease the chance of selecting an anomalous year. It is assumed that transportation costs are a linear function of distance (Backhouse, 1973, pp. 75-80).

Maxfield (1969) uses the transportation problem with transhipment points to study a similar issue. He considers the flow of hard red spring wheat from various production areas in the United States to different overseas markets using port terminals as transhipment points. In addition to using linear programming, rather than DSS, Maxfield's study varies from this thesis in two main ways. First, the problem is placed in an international context as opposed to a national one. Second, the purpose was simply to study the flows, not to base rationalization decisions on them.

Monterosso et al. (1985) adopt Ford and Fulkerson's (1962) linear programming model for determining the appropriate size and location of grain storage facilities in a developing country. The problem does not involve locating transhipment points, however it does demonstrate an application of linear programming to the storage of agricultural products. The model uses the Out-of-Kilter Algorithm (OKA) to optimize a capacitated network. Unlike the Transhipment Problem, the OKA does not assign supply and demand to nodes directly but rather it assigns flows to links connecting them. A transportation network was developed with farms (i) and potential delivery points (j) specified as nodes and the roads between them specified as links. Supply and demand levels are exogenous variables. The transportation and handling rates used were actual truck and rail tariffs (Monterosso et al, 1985, p. 105).

The OKA solves the problem heuristically. Initially the maximum possible capacity is placed on all links. The OKA then attempts to decrease overall costs by systematically reducing flows. It does so by reducing the demand at certain links to zero, while still requiring at least a given minimum amount of flow (grain) in the network. In this way the demand at certain sink nodes is reduced, and some of the links are removed. The minimum flow constraint is necessary because without it total costs would be minimized by simply reducing all flows to zero. The model considered only the farm to primary storage site aspect of grain movement. The objective was to minimize the total cost of grain transportation and storage (Monterosso et al, 1985, p. 102). Once the network associated with optimal grain movement was determined, facilities of an appropriate size to handle the required flows could be located. Once the optimal system of storage facilities was determined, sensitivity analysis was performed to determine the stability of the solution (Monterosso et al, 1985, p. 107). In this way it was possible to determine how suitable the solution would be under different production forecasts.

The model was tested using several regions in Brazil. The nature of the transportation network determined the pattern of storage facilities. In areas with poor connectivity and poor quality transportation infrastructure, transportation rates were higher. As such, the optimal solution contained a greater number of storage facilities in areas which were smaller in size and closer together than in areas with better connectivity (Monterosso et al, 1985, p. 106).

Scott (1971, p. 143) discusses the concept of myopic and dynamic linear programming. This technique incorporates both spatial and temporal dimensions and allows the optimal order of introducing facilities to be determined in addition to their spacing. This is useful in a planning context because the best method of introducing the new facilities, not simply the final configuration, is determined. The concept of dynamic linear and non-linear programming, including facility relocation over time is also discussed by Love, Morris and Wesolowsky (1988, pp. 60-94).

3.5 Decision Support Systems

Recently a new approach to solving facility location problems has been developed. This approach uses multiple criteria decision support system (DSS) software, rather than strictly linear programming techniques. DSS research has evolved from work on Management Information System (MIS) as a branch of Operations Research (OR). Operations Research developed in the military sphere but is now applied to most facets of society. It strives to apply scientific principles to management and logistics problems, especially those involving large systems (French, 1989, p. 17). MIS began in the 1950s but DSS work did not truly take off until the 1970s (Waters, 1988, p. 2). DSS are most suitable for problems with some structure, such that they can be handled by computer but which still require real expert input (Waters, 1988). They do not solve problems *per se* but rather they offer a choice of decisions to the user.

DSS allow for the use of multiple criteria, not simply transportation costs, in determining the optimal location for facilities. In this way, the needs and interests of all players can be considered. Some of these systems have a linear programming component, however they all allow for trade offs between several conflicting criteria.

Handler and Mirchandani (1979) discuss the concept of multiple criteria decision making, though not in a specifically DSS context. They review several approaches which can be taken toward reconciling conflicting objectives in a multiple criteria problem. These include optimizing the most important objective while treating the secondary objectives as constraints, i.e. they aim to optimize the primary objective such that the values of the secondary objectives do not exceed given specifications. Another approach is to score distance between a facility and demand point at an increasing rate, thus penalizing farther distances. The purpose is to minimize the average travelling distance.

French's (1989) collection of readings contain a number of case studies which make use of multiple criteria decision making techniques. The original works were published between 1969 and 1985, however most are from the early 1980s. The case studies include, among others: determining the best method of marketing a new product, evaluating risk in nuclear waste management and selecting a company for the award of a contract.

Tabucanon (1988, p. 1) discusses how weaknesses in classical economic theory has resulted in the increasing use of multiple-criteria decision making approaches. Classical economic theory is based on simple cost criteria and thus is not necessarily appropriate when addressing many complex, real-life decision situations. Multiple-criteria modelling often allows for the creation of more realistic, balanced scenarios.

Tabucanon (1988, pp. 5-11) defines Multiple Criteria Decision Making (MCDM) as having more than one criterion of which one or more must conflict with the other(s). Conflict is defined as an increase in the satisfaction of one criterion resulting in a decrease in the satisfaction of another. The criterion does not have to be economic in nature. In contrast to classical mathematical programming, the optimal solution does not satisfy each objective completely but rather produces the most satisficing overall solution. Satisfices is a term essentially meaning "best compromise" introduced by Simon in his seminal work, Models of Man (1957). Tabucanon also discusses some important MCDM concepts such as weighting, cutoff values and scale of measurement.

DSS consist of three main components. The first is a Data Base Management System (DBMS) which stores and organizes all data. The second is the Model Base Management System (MBMS) which organizes and creates the models which can be used with the data to investigate the decision. The third and final component of a DSS is the Dialogue Generation and Management System (DGMS) which represents the user interface (Malczewski, pp. 62-72).

There have been several reviews and evaluations of DSS in the literature (Armstrong et al., 1986; Densham and Rushton 1987; and Taylor and Taylor, 1987). In addition, there is considerable internal documentation in most DSS computer packages such as AIM, DAS, MATS and DINAS (Lotfi and Zionts, 1988; Armada Systems, 1990; Brown et al., 1986; and Ogryczak et al., 1988), respectively.

Malczewski provides an extensive overview of DSS and its application in the location decision making process. The report reviews the evolution of DSS and discusses the concept of location decision making as well as critically reviewing five specific DSS software packages. Malczewski states that the purpose of locational decision making is to "maximize the agreement among the interest groups" (p. 4) and that its purpose is to "support users of the system in achieving a higher effectiveness of decision-making while solving a semi-structured problem" (p. 49).

Malczewski discusses several weaknesses inherent in most existing DSS for location planning. The greatest weakness is the lack of support and structure in identifying the problem and suitably structuring it for the DSS (p. 9). The other area of weakness is the fact that the underpinnings of most DSS are based on the classical economic concept of the economic man. Classical theory assumes the decision maker is an "economic man" who bases decisions on factual, perfect knowledge (p. 10). Multiple objective problem solving approaches which try to avoid the classical assumption of economic man in favour of technical problems tend to lose theoretical ties however (p. 17).

Since multiple criteria decision making approaches such as those used in DSS attempt to reconcile conflicting objectives they can not truly optimize, rather they seek solutions which represent the best compromise, or are most "satisficing". This is not unlike the approach of game theory however the main weakness of game theory is the rigour of the assumptions, which are rarely met (Malczewski, p. 38).

Despite specific mention in the DINAS documentation about the suitability of the software for agricultural stores location problems (Ogryczak et al, 1988), the author is not aware of any DSS applications in the area of agricultural facility location. DSS have been used successfully in other location problems however. Massam and Malczewski consider four decision support systems in their work on locating rural health facilities in Zambia. One article deals specifically with one system, the network based DINAS (in press) and another (1990) compares the results of four different systems, AIM (Lotfi and Stanley Zionts, 1988), DAS (Armada Systems, 1990), MATS (Brown, Stinson and Grant, 1986) and DINAS (Ogryczak, Studzinski and Zorychta, 1988). In each case they consider criteria or variables representing a number of different factors in the evaluation of potential sites.

3.6. Summary

The htp elevator location problem using DSS requires an examination of three main bodies of literature. The three are: the rationalization of the Canadian grain handling and transportation system; mathematical modelling and location analysis; and DSS.

The grain handling system rationalization literature focuses on inefficiencies in the system and potential remedies. The work cited in the review is, on the whole, limited to the branch line and elevator issues. The mathematical modelling section covers the traditional, single criterion, linear programming quantitative approach to location problems. Specific examples of this approach to location problems, including grain movement and storage cases are cited. The final section, dealing with DSS covers two major areas of the literature. First the technical aspects of DSS are discussed and second, a series of case studies which use the DSS methodology are presented.

CHAPTER 4

DATA AND METHODOLOGY

4.1. Introduction

The following section outlines the data and methodology used in the study. The approach which will be taken to ascertain the optimal spacing distance for htp facilities on a Saskatchewan-wide basis, i.e. how far apart they should be, will be addressed first. Second, the method for determining the optimal location for a single htp elevator within an htp deficit study area will be discussed.

The distance associated with the equilibrium point between htp construction and operating costs on one hand and the cost of trucking grain on the other will be considered the optimal spacing for htp facilities. Costs for nine different types of truck and two elevator operating cost possibilities will be used in order to determine the optimal spacing under different scenarios.

Once the equilibrium elevator spacing has been determined a region which is not currently served by an htp facility will be identified. Both the warehouse problem of linear programming and DSS will then be used to identify the most satisficing htp elevator location within the area.

As discussed in previous chapters, the methodology is a framework for approaching the problem. The data values could vary however the method will not change, regardless of the values used.

4.2. Optimal Saskatchewan-wide HTP Elevator Spacing

In order to increase the efficiency of the grain handling and transportation system and thereby improve the competitiveness of Canada in international grain trade, it is hypothesised that improvements can be made in the Saskatchewan-wide spacing of grain elevators. This section determines the spacing required for the optimal htp elevator distribution. Once this optimal spacing of htp facilities is determined, the approximate locations of future facilities can be determined by interpolation from existing locations. The existing points must be used as starting points in order to maintain an appropriate spacing in a province-wide context.

The optimal spacing will be determined by finding the distance associated with the equilibrium point between trucking and elevator costs. Trucking costs favour a high density of facilities since this would result in decreased hauling distances, thus decreased expense. Elevator costs on the other hand favour few facilities, thus a lower density.

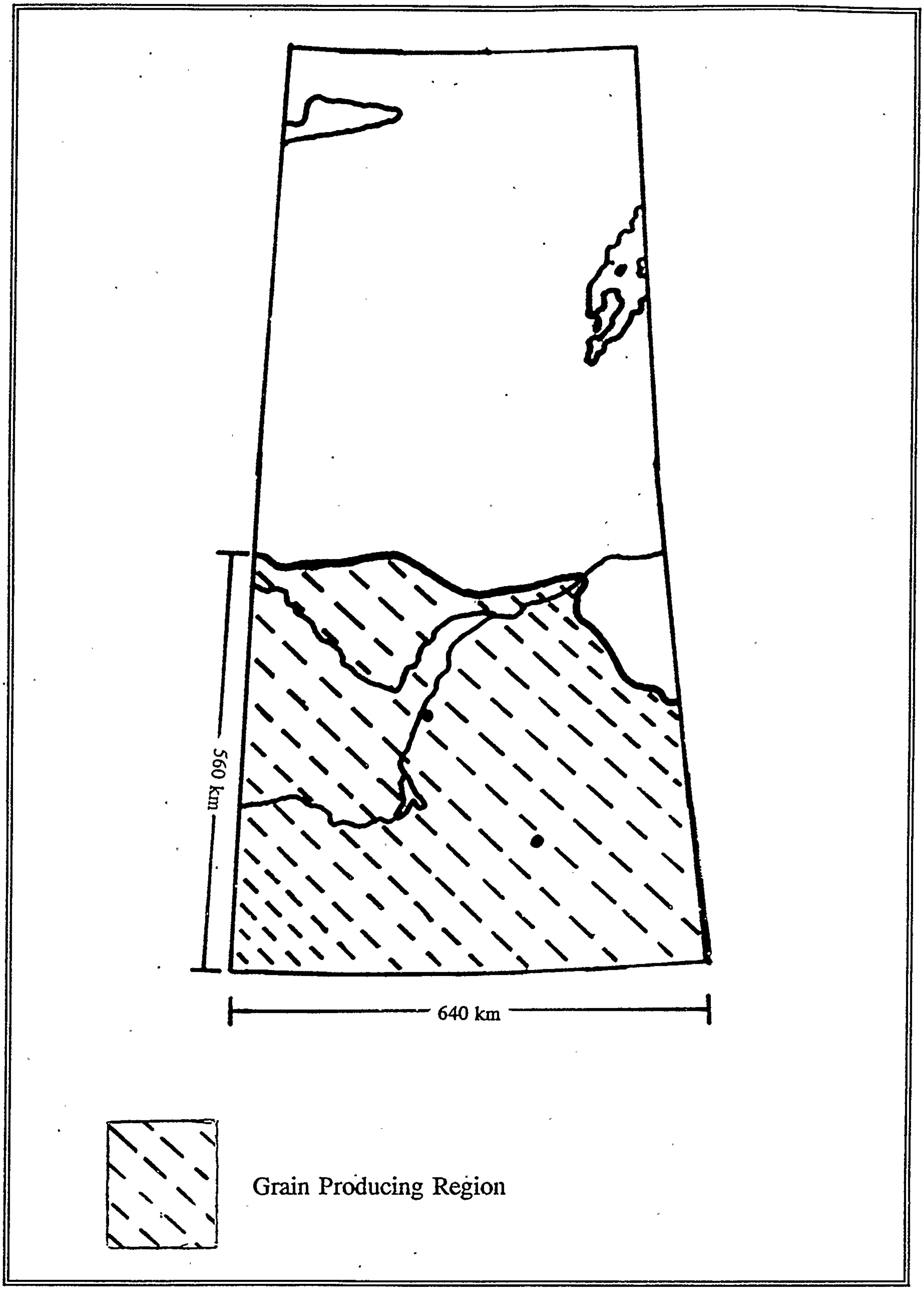
4.2.1. Elevator Costs

In order to determine the aggregate cost of an htp elevator system with a given spacing, the number of elevators required for that spacing must first be determined. Once this is complete and the cost of constructing and operating a single elevator is calculated, the aggregate cost of a Saskatchewan htp network can be determined.

The number of elevators required for any given spacing can be determined by dividing Saskatchewan's grain production area by the spacing. The grain production area is approximately 640 kilometers east/west by 560 kilometers north/south for a total of 340,2000 square kilometers (The New Canadian Oxford Atlas, 1985, p. 31). It is shown in Figure 4.1.

Once the number of elevators required is determined, the total cost of the htp network can be calculated by multiplying the number of elevators by the cost per facility. Elevator costs can be broken down into two main components: capital and operating. The capital cost (C_c) used in the analysis is a combination of the construction costs and the cost of servicing this capital, i.e. the interest. An interest rate of 10% is assumed for the study. This is higher than present interest rates however the current interest rates are very low and it is reasonable to expect that over the amortization period they will rise to or possibly exceed the 10% level. The amortization period used will be 15 years. The elevator construction costs used are for those htp facilities currently being built. Although the construction costs vary somewhat, a figure of 1.92 million dollars per unit will be used for the analysis. This is the Alberta Wheat Pool's projected cost for a htp

Figure 4.1: Saskatchewan's Grain Producing Region



Source: The New Canadian Oxford Atlas, 1985, p. 31

facility about to enter the construction phase at Morrin, Alberta (Alberta Wheat Pool, June 1992). Actual operating costs have not been released by elevator companies and will therefore be estimated. Two annual operating cost scenarios, \$100,000/year and \$250,000/year will be used to test the model under different conditions. The lifetime of an htp facility is considered to be 50 years. The fifty year figure is taken from the lifetime projection made by the Alberta Wheat Pool for its new Morrin facility (June, 1992). Based on these assumed per facility variables, the cost of operating an htp elevator network can be calculated as follows:

$$C_t = n(C_c + (50 \times C_o))$$

Where:
- C_t = Total Aggregate Elevator Cost (\$)
- n = number of facilities
- C_o = Annual Elevator Operating Costs (\$)
- C_c = Elevator Capital Cost (Construction costs and debt servicing costs) (\$)

$$C_c = C_{PV} \times (1 + i)^n$$

Where:
- C_c = Elevator Capital Cost (Construction costs and debt servicing costs) (\$)
- C_{PV} = Capital Investment Cost (\$1.92M)
- i = interest rate (10%)
- n = amortization period (15)

Therefore:

$$C_c = PV \times (1 + i)^n$$
$$C_c = 1.92M \times (1 + .1)^{15}$$
$$C_c = \$8.0203\ M$$

Inflation is not included in the expense calculation because it will affect both elevator and trucking costs, shifting both curves upward. Assuming that the inflation rate is comparable for both the trucking and elevator sectors, the two effects will cancel each other out and thus, although the equilibrium cost will increase, the equilibrium distance will not change.

As shown in Figure 4.2, elevator service areas are diamond shaped. This is due to the assumption that grain is trucked primarily along the grid iron road allowance system. Larson and Stevenson (1972; in Erlenkotter, 1987, p. 6) have shown that when the Manhatten metric is used that the most efficient market shape is the diamond.

4.2.2. Trucking Costs

Regression models will be developed to determine total elevator and total trucking costs. The models will be generated from known costs at five htp spacings: 20, 40, 80, 160 and 320 kilometres. Trucking costs for the maximum hauling distance for these five spacings have been taken from Meyer and Sparks (1987, p. 332). The maximum hauling distance is the farthest that any producer, located on the boundary of two elevators' service areas would have to haul. This concept is illustrated in Figure 4.3 using the 20 kilometer elevator spacing as an example. It shows that if the htp spacing is 20 kilometers apart, the furthest distance which must be travelled to reach an elevator is 10 kilometers, therefore the maximum hauling distance is 10 kilometers.

Meyer and Sparks (1987) determined the cost of hauling grain for each of nine different types of truck ranging from small, private vehicles to large custom and commercial trucks. The truck types and their associated costs at selected elevator spacings are shown in Table 4.1. Trucking costs are not linear over distance. Increased

Figure 4.2: Delivery Point Service Areas

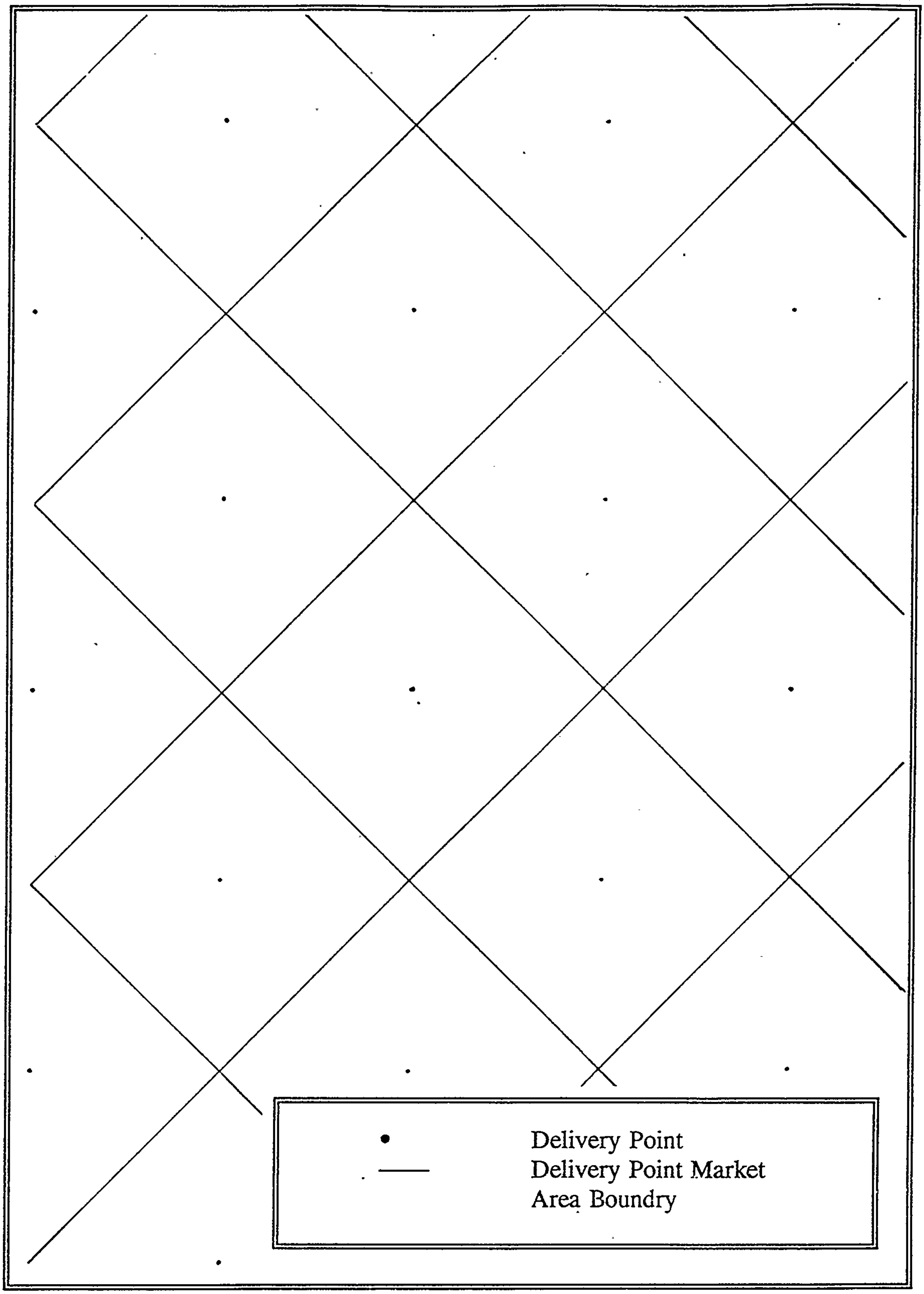
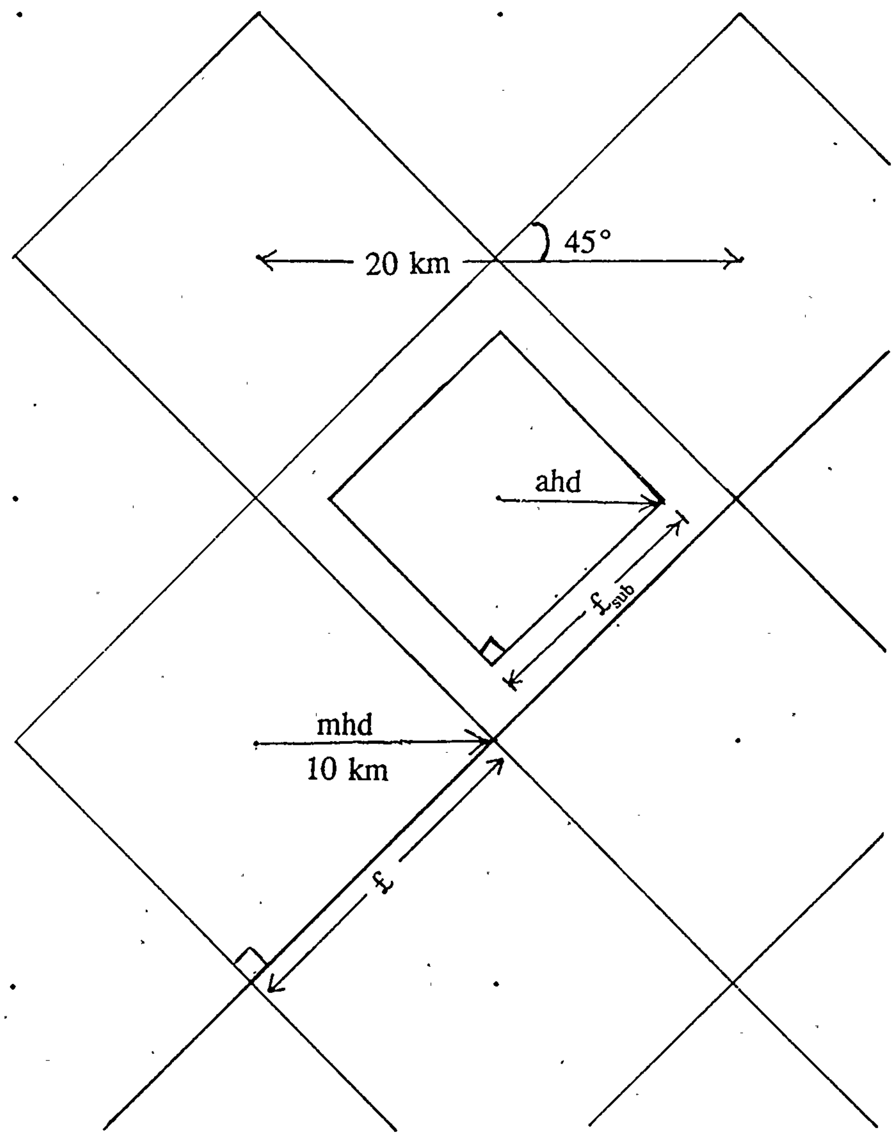


Figure 4.3: Delivery Point Maximum and Average Haul Distances



distance spreads fixed costs thus lowering average fixed costs per unit of distance and consequently lowering average total costs. As such the regression model will be used to determine costs at intermediate points. Once the model is developed, it will be possible to extract the equilibrium spacing distance between the various trucking costs and elevator costs by setting the two regression formulae equal to each other and determining the intercept.

Table 4.1: Trucking Rates for the Maximum Hauling Distance (km) at Selected HTP Elevator Spacings ($/tonne)

	20	40	80	160	320
PRIVATE TRUCKS					
2 axle	7.9	11.16	15.34	21.75	38.26
3 axle	5.45	8.70	13.21	18.83	27.86
3 axle with pup	5.15	7.39	11.57	15.96	22.19
5 axle	5.25	8.94	14.7	22.45	31.61
A-train	3.69	6.47	11.15	18.15	27.17
CUSTOM TRUCKS					
3 axle with pup	2.96	3.93	5.35	7.79	13.37
5 axle	3.88	5.27	7.58	12.16	20.19
A-train	2.86	4.11	5.58	8.71	15.17
COMMERCIAL TRUCK					
A-train	1.13	1.72	2.87	5.15	9.66

Source: Meyer and Sparks, 1987, p. 332

The total cost of transporting the Saskatchewan grain crop will be determined be applying Meyer and Sparks' (1987, p. 332) trucking tariffs to the 1979-80 to 1989-90 ten year average for Saskatchewan crop production of 15,641,100 tonnes (Canadian Grain

Commission, Economics and Statistics Division A, 1989-90, p. 34). For each distance and mode scenario the 50 year total transportation costs are calculated as follows:

$$C_{XM} = 50\ (.7071\ t_{XM}\ \times\ 15{,}641{,}100)$$

Where:	C_{XM}	=	Total Transportation Cost ($)
	t_{XM}	=	per tonne cost of transporting grain distance X by mode M
	X	=	Maximum Hauling Distance for the Given Spacing (km)
	M	=	Mode

The per tonne cost of transporting grain distance X by mode M (i.e. t_{XM}) is multiplied by .7071 as a form of determining the average transportation costs for the given spacing. If, for example, the spacing is 20 kilometres recall that the maximum hauling distance would be half the spacing distance, or 10 kilometres. The tariffs quoted in Table 4.1 for each spacing are for this maximum hauling distance. Assuming producers are located at a uniform spacing, the average hauling distance for a given delivery point is .7071 (or 70.71%) of the maximum hauling distance. This is because this distance marks the boundary which divides the number of producers hauling to that delivery point in half. This is to say that, for any given delivery point service area, half of the producers are located greater than 70.71% of the maximum hauling distance away from the delivery point and the other half are 70.71% of the maximum hauling distance closer to the point.

The steps in calculating average haul distance are as follows. First the total area of each elevator service area must be determined. This is because, since the producers are assumed to be evenly distributed, the average haul distance represents the boundary of a sub-service area, within the main service area, which contains half the total service area, thus half of the producers. As demonstrated in Figure 4.3, the length of one side of the service area, £, can be calculated as follows:

$$£ = \text{sine } 45° \times S_e$$

Where:	£	=	length of one side of the service area
	S_e	=	Elevator spacing

Therefore, if for example the spacing S_e is 20 kilometers £ can be calculated as follows:

$$£ = \text{sine } 45° \times 20 \text{ km}$$

$$= 0.7071 \times 20$$

$$£ = 14.142 \text{ km}$$

The size of the elevator service area is then simply "$£^2$". For the example with a 20 km elevator spacing, the service area size can then be calculated as follows:

$$"£^2" = 14.142^2 = 200 \text{ square km.}$$

Once the service area size is known, the average hauling distance can be calculated by determining the distance which encloses a sub-service area which is half of the total service area in size. For the example used this is half of 200 square km or 100 square km. The sub-service area which contains half of the producers is therefore "$£_{sub}^2$" or 100 km. Reversing the previous calculations produces the average hauling distance.

$$"£_{sub}^2" = 100 \text{ square km}$$

$$£ = 10 \text{ kilometers}$$

This means that the length of one side of the service area is the square root of the sub-service area's size. The general formula for the average hauling distance (ahd) for a given elevator service area is then as follows:

$$\text{ahd} = \text{sine } 45^\circ \times £$$
$$= .7071£$$

This can be generalized as: the average hauling distance for a diamond shaped service area with side lengths of £ is 70.71% of £.

4.3. HTP Elevator Location Case Study

4.3.1. Introduction

The following section outlines the approach used in optimizing the problem using both the warehouse transportation problem and DSS. It also discusses both the four DSS and seven objectives which will be used in the analysis.

Initially TSA88 (Eastern Software, 1984), a warehouse transportation problem software package will be used to determine which delivery point represents the optimal htp site in the (htp deficient) study area. This and other transhipment linear programming packages optimize solely on the basis of a single criterion, transportation cost. The solution produced by this package will be compared with those determined by the four DSS listed below. It is hypothesized that the DSS will not select the same site as the warehouse linear programming package because the former are able to incorporate multiple criteria in the optimization process i.e., they are not limited to a single one.

The DSS which will be used are: DINAS - Dynamic Interactive Network Analysis System (Ogryczak, Studzinski and Zorychta, 1988); DAS - Decision Analysis System (Armada Systems, 1990); MATS - Multi Attribute Trade-off System (Brown, Stinson and Grant, 1986); and AIM - Aspiration-level Interactive Method (Lotfi and Zionts, 1988). They will determine the optimal htp location within the study area in terms of the interests of the six major players involved: the producers, elevator companies, railway companies and municipal, provincial, and federal governments. These interests are represented by a set of seven objectives which are discussed in detail in section 4.3.4. which concerns the DSS variables. The objectives will be traded off until a solution with criteria which is acceptable to all is derived. The solution is not likely to be the optimal for any given interest group however it will represent the best compromise, or most satisficing location.

4.3.2. Problem Structure

For both solution methods, the problem will be formulated in a similar fashion. Farms represent grain supply points. All farms are assumed to produce 1400 tonnes of grain which must be moved through the elevator system and on to port. This value has been selected because it is much larger than the actual average per farm tonnage produced and in this way future routing will not be hampered by a system which is under-capacitated. To simplify distance measures when determining grain shipping costs, farm sites are assumed to be located at the intersection of road allowances. The Saskatchewan road network has gravel road allowances every mile east-west and every two miles north-south. The rectangular area enclosed by the road system is two sections of land, which is the approximate average farm size in the province (Census of Canada, 1986). To further simplify the data, the product of the four farms located at an intersection will be aggregated. Thus, the "farms" discussed from this point forward in the paper are actually the aggregation of four farms.

The major Canadian grain handling ports of Vancouver, Prince Rupert, Churchill, Armstrong and Thunder Bay represent the demand nodes. The terminal nodes, and the arcs connecting them to the potential htp elevator sites are considered uncapacitated because the amount of grain shipped from the study area will be of relatively little consequence to overall deliveries and as such, terminal and arc capacities will not be a factor in determining the specific htp location. This is accomplished indirectly by setting extremely large capacities, much larger than the quantities of grain which will be generated within the study area. The issue of capacity is only a factor when using the DINAS system. The other three DSS do not analyze the data in a network sense and as such, node and arc capacities are not a consideration.

The towns in the study region which are currently grain shipment points are the final set of nodes. They represent transhipment points and have no intrinsic supply or demand quantities themselves. It is assumed that changes in the primary elevator system must occur within the existing location context, therefore, no new delivery points, i.e., elevator locations may be established. This is a realistic assumption since existing delivery points already have the railway sidings, service roads and other infrastructure required by elevators. As such, the issue becomes one of whether to increase or totally remove capacity at a given delivery point, or town.

Shipping distance along the road network from farm to elevator will be used as a surrogate for shipping costs because, without knowing the truck type which will be used for shipping, actual trucking costs cannot be calculated. In most cases the prairie grid iron road allowance system must be used for transport from the farm to the primary elevator however, the Manhatten distance is sometimes reduced if producers are able to take advantage of highways which angle across the road allowances.

Published Western Grain Transportation Act (WGTA) railway freight rates for grain, the aggregate of the producer's and government's share, will be used as cost coefficients from elevator to port.

4.3.3. DSS Concepts

Although individual DSS vary somewhat in their solution methods, those used in this study are all built on similar concepts. These concepts and general solution methods will be briefly reviewed. Note that, although the current problem uses DSS in a location analysis context they are not necessarily limited to spatial problem applications. Any problem requiring the identification of an optimal choice from a set of possibilities would be a candidate for this type of analysis.

Figure 4.4: MATS Algorithm for Computing Plan Scores

$$\text{Plan Score}(k) = \sum_{i=1}^{nfac} (wgt(i) * util(i,k))$$

Where:

k = plan
nfac = number of factors in project
wgt(i) = standardized weight of factor i

$$wgt(i) = \frac{wgt(i)}{\sum_{j=1}^{nfac} wgt(j)}$$

hence:

$$\sum_{i=1}^{nfac} wgt(i) = 1.\phi$$

util(i,k) = the value of the utility function of factor i, at impact k

Source: MATS-PC Manual (Brown et al, 1986, p. 12)

Applied in a spatial/location analysis context, DSS require a set of nodes (possible sites) as well as criteria with objective functions and utopia, nadir, aspiration and reservation levels for each of the criteria. Utopia and nadir values are the maximum and minimum values for a given criteria and aspiration and reservation levels are the desired and minimum acceptable levels respectively for the criteria. All DSS used in the study are interactive, thus these levels may be adjusted during the analysis. Some DSS also allow for the inclusion of cut-off values and weights. Unlike the reservation level which is a level that it is suggested should not be passed, cutoff levels are an absolute value for a criteria which must not be violated in the final solution. Weights for criteria are simply an indication of their relative importance.

The actual method used to solve the location selection problem varies among the different DSS. The MATS program uses the algorithm listed in Figure 4.4 to determine a "plan score" for each node. The nodes are then ranked according to their plan score.

DINAS works by transforming potential nodes, or possible sites, into artificial arcs and selecting the flow route through them which is most satisficing. The problem is solved through the program's TRANSLOC solver. The solver is based on the branch and bound approach and uses the simplex special ordered network algorithm. The complete algorithm listings can be found in the DINAS manual (Ogryczak, 1988, pp. 4-13).

The DAS system uses a number of different approaches to order the set of nodes (alternatives) from best to worst. The first step involves searching the alternatives for ones which are dominated and for those with criteria which violate cutoff levels. Dominated alternatives are those for which one or more other alternatives are superior in terms of at least one criterion and equal or better in all other criteria. Once these sub-standard alternatives have been identified and the user is given the option to eliminate them from further analysis, the evaluation proceeds. Four different techniques: The Linear Assignment Method, Normalized Additive Weighting, ELECTRE and TOPSIS are used to rank the alternatives. The theory and algorithms for these techniques can be found in Hwang and Yoon, (1981). Three methodologies are then used to aggregate the results of the ranking procedures in order to determine the overall ranking. The first of these orders the alternatives by determining their mean rank, calculated from its four independently derived ranks. The second ranks them according to the number of "wins" they score and the third, by the number of "wins" minus the number of "losses". Following this, an overall rank is assigned to each alternative (Armada Systems, 1990, p. 5-6).

The DINAS system is of particular interest. First, it is the only DSS specifically designed for multi-facility location problems. The other DSS can handle single, but not multiple facility location problems. DINAS, a network based DSS, also maintains the spatial structure of the data and is specifically designed to handle commodity flow problems.

4.3.4. DSS Variables

Whereas the Warehouse problem used only a single variable, transportation costs, DSS are able to make use of a number of variables concurrently in analyzing a problem. As a result, both equity and efficiency objectives can be included in the same analysis. The variables which will be used for this problem are listed in Table 4.2.

The variables have been chosen to reflect the interests of the six major players in the grain handling and transportation system. These players and their interests were identified by Meyer and Sparks (1987). It is the sometimes conflicting interests of these players which must be traded off until a compromise acceptable to all is reached.

Table 4.2: DSS Variables

Variable Name	Objective	Measurement Units	Variable Description
Ship	Minimize	dollars	Aggregate transportation costs when using the given shipping point
20M	Minimize	producers	Number of producers greater than twenty miles from the delivery point
10M	Maximize	producers	Number of producers within a ten mile radius of the delivery point
Main	Minimize	miles	Distance to the main rail line
Farthest	Minimize	miles	Hauling distance for the producer located furthest from the delivery point
Curcap	Maximize	tonnes	Current elevator capacity at the delivery point
Roadac	Maximize	mph	Speed limit on main access road to delivery point

The first interest group is the grain producers themselves. An efficient grain handling and transportation system is desirable for this group because the more economically grain can be shipped, the more competitive it becomes on the world market. Producers however are also interested in minimizing their own individual transportation costs to the elevator and as such desire a relatively close network of elevators.

Several of the objectives are directed toward the producers; these are: the number of producers within a 10 mile radius of the delivery point (10M), the number of (study area) producers greater than 20 miles from the delivery point (20M), the distance of the farthest producer from the delivery point (Farthest) and the transportation cost associated with moving the grain from the farms, through the delivery point and on to port (Ship). In DINAS, the cost coefficients for "Ship" are the only ones assigned to the arcs between the nodes. They represent the cost of moving one tonne of grain that distance. All other coefficients are assigned to the town nodes. With the other three systems, all coefficients are assigned to the town nodes and "Ship" represents the least aggregate cost of getting grain to a terminal using that delivery point.

The second group of players are the railway companies. They argue that they operate an overbuilt system of branch lines which are the product of an overly competitive period at the beginning of the century. The railways are anxious to abandon many of these branch lines or at least sections of them, especially those whose traffic consists only of small amounts of grain. The railways would like to see grain delivery points located either along main lines or branch lines which will generate a relatively large volume of traffic. Most existing prairie branch lines are protected by statute until the year 2000 (Wilson, 1981). After this date abandonment may proceed. For the purposes of this study, all branch lines will be considered candidates for abandonment because, when constructing a long term facility such as an htp terminal, it is important to consider the future situation, rather than simply the current one. As such, low volume lines may dramatically increase in volume and vice versa once htp elevators are constructed and delivery patterns change.

The railway's interests are reflected most strongly in the "Main" objective which seeks to minimize the number of miles along the branch line the delivery point with the htp elevator is from the railway main line. The companies would like to see this objective minimized as it could mean that all or a portion of a line(s) could be abandoned. This would result in savings through lowered maintenance costs and decreased time operating on the branch line. The reduction in branch line mileage is desirable from their perspective because trains must operate at reduced speeds on them. As such it is more costly to operate on a branch line than a main line.

Elevator companies, similar to the railway companies, are interested in rationalizing their network of facilities which was designed for a different era. In doing so, it is desirable for them to retain customer goodwill and select a site which will best serve their customers. The "Curcap" objective represents the current elevator storage capacity, in tonnes, at each delivery point. It has been included because it is somewhat representative of the current delivery patterns in the area.

The provincial and municipal governments, comprising the fourth and fifth groups, are somewhat interested in maintaining a close network of elevators, or at least an htp location which would minimize aggregate shipping distance. The provincial government is responsible for maintaining and building highways and the municipal government is responsible for secondary roads. The farther apart the elevators are located the more trucking must occur. To increase hauling efficiency, larger trucks are used, thus increasing wear on the road network. The governments are thus responsible for greater road expenses with no corresponding increase in revenue. As such, like the producers the interests of these levels of government is represented by "Farthest", "10M" and "20M". In addition, the "Roadac" objective is relevant. To accommodate large numbers of large grain trucks, the access road to the htp elevator should be paved and of relatively high quality. For this study, speed limit on the main access road to the town is used as an indicator for road quality.

The final player in the system is the federal government. The federal government's interest is in delivering grain to buyers at the most competitive price possible since grain is an important foreign exchange earner for the country. In addition, it is interested in reducing the level of subsidization that it now provides to the industry. This includes transfers to rail companies which are legally required to haul grain on protected branch lines. As such, a number of the objectives are important to this player. These are: "Ship" and "Main" from both an economic and political perspective, as well as "20M", "10M" and "Farthest" from a political perspective.

4.3.5. Objective Weights

The delivery points will be evaluated using the criteria in both an unweighted and weighted fashion. The initial evaluation will use unweighted criteria. Under this analysis, both the aspiration (desired) and reservation (minimum acceptable) levels are set to the utopia (best possible) levels for each criterion.

The seven criteria are not necessarily all of equal importance however. Some of them have appeared as more important in popular, technical and academic literature. In the second evaluation, criteria are weighted as follows (out of 100):

100 • Aggregate transportation costs when using the given shipping point (Ship)

• Number of producers within a twenty mile radius (20M)

• Distance to the main rail line (Main)

75 • Number of producers within a ten mile radius (10M)

50 • Hauling distance for the producer located furthest from the delivery point (Farthest)

• Current elevator capacity at the delivery point (Curcap)

25 • Speed limit on main access road to delivery point (Roadac)

Although all variables have been selected because they represent concerns of the major players, this weighting has been selected because it gives priority (greatest weighting) to three of the greatest concerns of the groups most directly influenced by rationalization: the government, the producers and the railways. The number of producers with a relatively long hauling distance (20M), the number of branch line miles involved in the moving the grain (Main) and the overall cost of shipping grain (Ship). "Ship" is a priority of all groups since minimizing the cost of grain movement is in every ones best interest. "10M" is weighted slightly lower because it is not completely independent of "20M". "Curcap" and "Farthest" have been weighted at half the maximum. In the case of "Farthest" this is because, although it is important that no producer haul exorbitant distances, the variable measuring the interests of a single producer should have a lesser impact than the variables measuring the interests all producers ("10M" and "20M").

"Curcap" is given a lower rating because, although it is a indicator of current delivery patterns, it will not necessarily be important in terms of new delivery patterns. The lowest weighting is given to "Roadac" because this varies relatively little among most towns. The precise weightings are not of great concern since these can be adjusted in subsequent sensitivity analysis which are discussed below.

DAS and MATS allow the user to specify the weight to be assigned to each criterion directly. As such, the weighting process is relatively straight forward with these systems. DINAS and AIM do not have a weight assignment option and as such, weights must be assigned indirectly. This is accomplished by lowering the aspiration level on those criterion which have lower weightings.

4.3.6. Sensitivity Analysis

As with any location analysis, when using DSS to locate htp facility sites it is important to determine not only the optimal site but also the stability of the solution. That is to say, it is important to determine the magnitude of change in the coefficients of the criteria which will cause a change in the optimal solution. Ideally, the location chosen will be highly stable and thus require a relatively large change in some or all of the parameters to shift the optimal site. When locating a long term facility such as an inland terminal it is important for the site selected to be stable as some or all of the criteria coefficients may change over time.

TSA88 has a built in function for performing sensitivity analysis. The program indicates the amount of change in supply and/or demand required at each node to shift the optimal solution.

With the exception of MATS, none of the DSS used have a built in capacity for sensitivity analysis however, by repeatedly adjusting the aspiration/reservation levels for the objectives a type of sensitivity analysis can be performed. Evaluating all possible combinations of objectives with varying aspiration and reservation levels would be an extremely complex process which would produce much unnecessary data. As such, a limited number of key configurations will be used to test the sensitivity of the DSS solutions.

The sensitivity test involves relaxing the aspiration levels of each of the seven objectives one at a time, while the aspiration levels of the remaining six objectives are set to their utopia values. Each time the aspiration level is lowered, the problem will be re-optimized. If the selected location does not change, even when the aspiration level is set to the nadir level, it is assumed that the solution is not very sensitive to changes in the criteria variables, i.e. that it is stable. This means that the selected location can be used with considerable confidence because, even if the current coefficients for the objectives change, it will remain the optimal location. If the optimal location does not shift when an objective's aspiration level is set either at the nadir or at the utopia levels the objective can be considered relatively unimportant in terms of the objective trade offs.

Unlike the other DSS used, MATS has a type of built in sensitivity analysis which allows the user to compare two alternatives (potential htp locations) at a time. For any given criterion, MATS indicates the magnitude of change required in the coefficient for one alternative in order to make the plan scores, i.e. rank, for the two alternatives equivalent.

4.4. Summary

The chapter has outlined the procedures for determining both the optimal Saskatchewan-wide htp elevator spacing and the specific location for one facility in an htp-deficit region. The methodology is the central focus of the thesis as a whole. It is flexible and can be used in any bulk commodity warehouse location problem, regardless of the size and locale. The data used is a combination of empirical values adopted from other studies and estimates derived using informed assumptions. While every attempt has been made to have the most accurate data possible in order to produce realistic results, the appropriateness of the methodology, not the data is of primary importance.

The major steps in the spacing and location study are as follows. First, based on known costs at five possible spacing distances, 20, 40, 80, 160, and 320 kilometers, regression models for each of the nine truck types and two per year elevator operating cost scenarios will be developed. The regression formula for each of the truck types in turn is then set equal to both of the elevator cost formulae in order to determine the equilibrium spacing for each combination. Based on these equilibrium points, a general spacing will be determined which will reflect current grain trucking trends. Once the optimal spacing has been determined, an htp-deficit region can be selected as the basis for an htp elevator location case study. The primary tool for location selection is multiple-criteria DSS, although the single criterion warehouse problem of linear programming is used for a comparison. The DSS evaluate each potential htp site, i.e. active delivery point, within the study area concurrently in terms of several conflicting objectives, which represent the interests of the major players in the issue. Once a potential htp site is identified, sensitivity analysis will be performed to test the stability of the solution.

CHAPTER 5

RESULTS AND ANALYSIS

5.1. Introduction

The ideal htp elevator spacing on a Saskatchewan-wide basis has been determined by developing a regression model for each of the trucking and elevator costs in turn against spacing distance. The formula for each of the nine types of trucking in turn are then set equal to the two elevator formulae in order to determine the equilibrium htp spacing for each truck type and elevator cost scenario. Based on the equilibrium spacing under these various conditions, a final spacing will be chosen. Other requirements for elevator locations will also be discussed.

Once the spacing is known an htp deficit region and potential htp sites within it will be identified. The characteristics of the optimal site selected, with both an unweighted and weighted set of seven objectives will be discussed. As well, the stability of the solutions will be explored. Finally, the analytical software used, TSA88 and the four DSS will be critically reviewed.

5.2. Macro Study

5.2.1. Ideal Spacing

The initial analysis determines total trucking and elevator costs over the 50 year elevator lifespan from the known costs at five spacing possibilities. From these known costs a regression model is built for each truck/elevator cost combination. The number of htp facilities required at the five spacings for which trucking costs are known is shown in Table 5.1. The numbers were generated by dividing the total Saskatchewan grain production area of 340,2000 square kilometers by the selected spacings shown. These figures are used to generate the total elevator costs for each known spacing shown in Table 5.2. Table 5.2 also shows the 50 year costs for each of the trucking types at the five known spacings.

Table 5.1: Number of HTP Elevators Required at Selected Spacings

Spacing (km)	20	40	80	160	320
Number of Elevators	896	224	56	14	3.5

Using the data from Table 5.2, the best fit regression for both the trucking and elevator costs (the dependent variables) against distance (the independent variable) is a double log model. In this model, the common log of each of the dependent variables is regressed in turn against the common log of distance for the 20, 40, 80, 160 and 320 kilometre spacings. The resultant regression formulae are shown in Table 5.3. As indicated by the negative slope value for elevator costs, they are indirectly related to distance. Thus, as distance (spacing) increases, elevator costs decrease. Conversely, trucking costs are directly related to distance, increasing as distance increases.

Table 5.2: 50 Year Elevator and Trucking Costs at Selected Spacings (x 10^8 dollars)

Spacing (km)	20	40	80	160	320
ELEVATORS					
With $100,000/yr					
Operating cost	116.7	29.17	7.29	1.82	0.5
With $250,000/yr					
Operating cost	183.9	45.97	11.49	2.87	0.7
PRIVATE TRUCKS					
2 axle	43.7	61.7	84.8	120.0	212.0
3 axle	30.1	48.1	73.1	104.0	154.0
3 axle with pup	28.5	40.9	64.0	88.3	123.0
5 axle	29.0	49.4	81.3	124.0	175.0
A-train	20.4	35.8	61.7	100.0	150.0
CUSTOM TRUCKS					
3 axle pup	16.4	21.7	29.6	43.1	73.9
5 axle	21.5	29.1	41.9	67.2	112.0
A-train	15.8	22.7	30.9	48.2	83.9
Commercial Truck					
A-train	6.3	9.5	15.9	28.5	53.4

The extremely high R-squared values ranging between .981 and 1 demonstrate the extremely good fit of the lines, with virtually no residuals. Note that the R-squared value of 1 for elevator costs is due to the fact that elevator costs were generated from a distance based model. As such they create a perfect fit when re-entered into a mathematical (regression) model. The Student's t-test t-values for the regressions are also listed in Figure 5.3. The critical values for the t-test are as follows: 2.35 at the

90% confidence level, 3.18 at the 95% confidence level, and 4.54 at the 99% confidence level and as such, all regressions are significant. That is to say, the regressions are all significantly relationships, they are not random.

Table 5.3: Trucking and Elevator Costs Regression Formulae

Y Variable	Regression Formula	R^{2*}	t value
PRIVATE TRUCKS			
2 axle	log(y) = .552 log(x) + 8.902	0.985	13.89
3 axle	log(y) = .582 log(x) + 8.738	0.997	33.20
3 axle pup	log(y) = .533 log(x) + 8.767	0.997	29.30
5 axle	log(y) = .746 log(x) + 8.433	0.965	9.10
A-train	log(y) = .724 log(x) + 8.388	0.996	26.91
CUSTOM TRUCKS			
3 axle pup	log(y) = .533 log(x) + 8.49	0.981	12.52
5 axle	log(y) = .597 log(x) + 8.523	0.989	16.08
A-train	log(y) = .589 log(x) + 8.407	0.987	14.89
COMMERCIAL TRUCK			
A-train	log(y) = .777 log(x) + 7.752	0.994	1.72
ELEVATORS			
operating costs $100,000/yr	log(y) = -2.0log(x) + 12.669	1.000	303800000
operating costs $250,000/yr	log(y) = -2.0log(x) + 12.867	1.000	1719000000

* Each of the R^2 values has 4 degrees of freedom

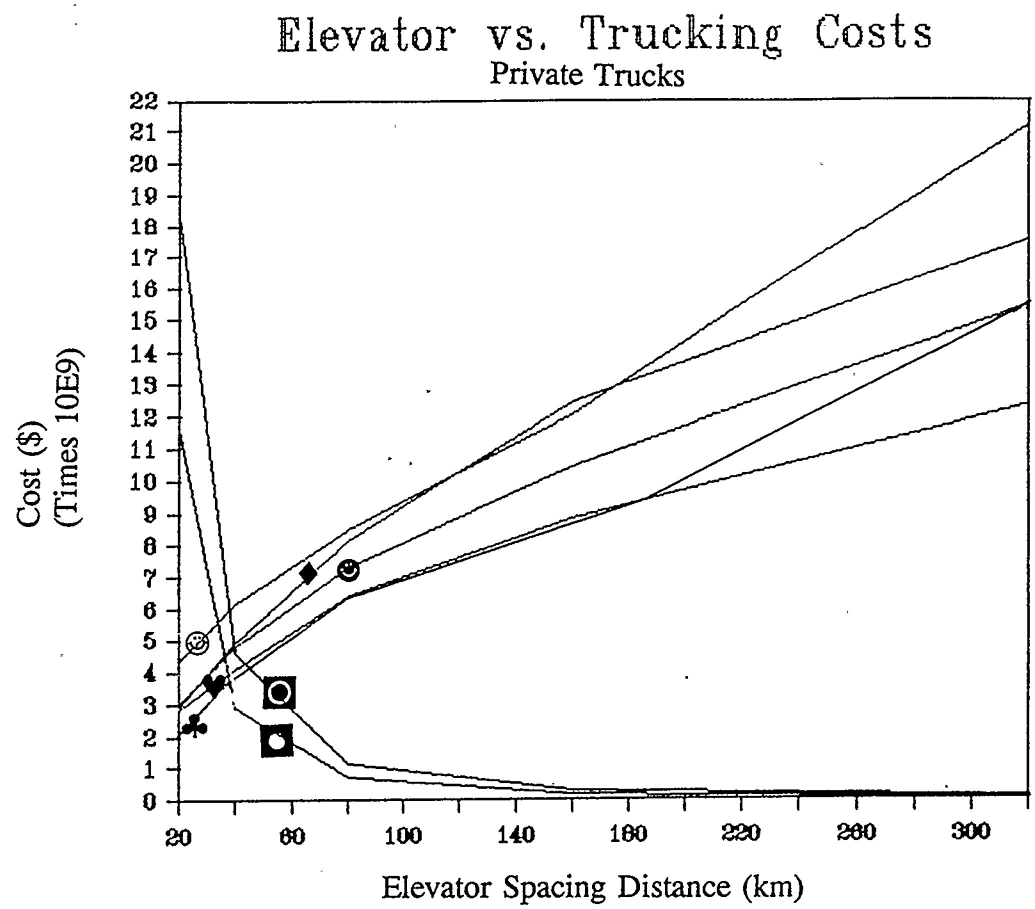
The equilibrium distance point between elevator costs on one hand and each of the nine trucking costs on the other are listed in Table 5.4, adjacent to the applicable trucking type. These were determined by setting the elevator costs' regression formula against each of the trucking costs' formulae in turn. The intercepts are shown graphically in Figures 5.1 and 5.2.

Table 5.4: Trucking/Elevator Costs Intercept Points

	Elevator Operating Costs: $100,000/yr		Elevator Operating Costs: $250,000/yr	
Y Variable	log(x)	km	log(x)	km
PRIVATE TRUCKS				
2 axle	1.476	30	1.554	36
3 axle	1.522	33	1.599	40
3 axle pup	1.540	35	1.619	42
5 axle	1.543	35	1.615	41
A-train	1.572	37	1.644	44
CUSTOM TRUCKS				
3 axle pup	1.65	45	1.728	53
5 axle	1.596	39	1.673	47
A-train	1.646	44	1.722	53
COMMERCIAL TRUCK				
A-train	1.771	59	1.842	70

Depending on the truck type and elevator operating cost scenario, the equilibrium elevator spacing varies between 30 and 70 kilometers. The ideal spacing should reflect the current and predicted trucking trends toward larger vehicles, particularly custom and commercial haulers (Chaudhary, 1985; Chaudhary, 1986; Chaudhary, 1987a). As such, a spacing of between 40 to 60 kilometers would be suggested because this is the approximate range of larger volume private as well as custom and commercial hauler equilibrium distances. This favours the more cost effective custom and commercial

Figure 5.1



☺ 2 Axle

☻ 3 Axle

♥ 3 Axle with Pup

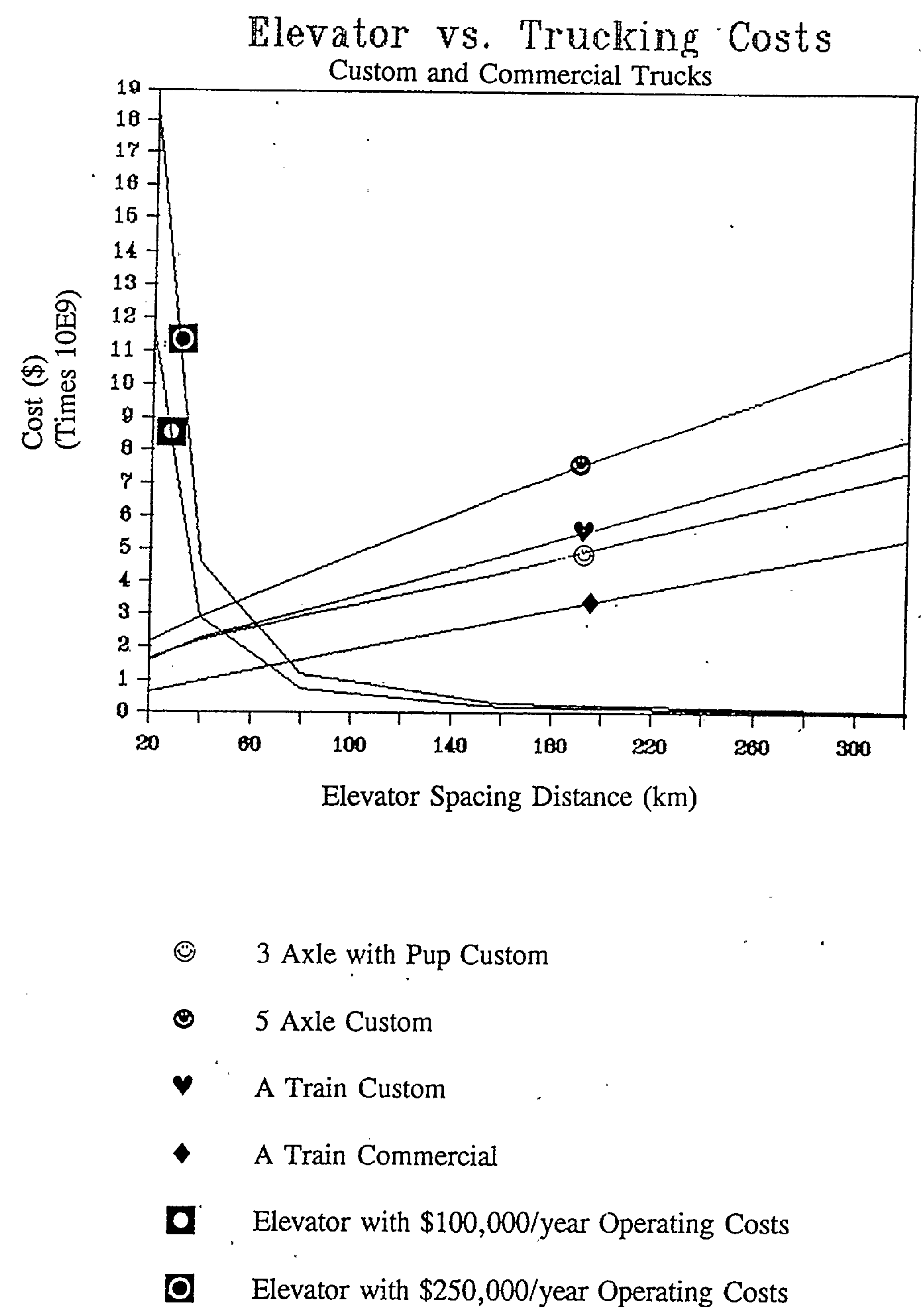
♦ 5 Axle

♣ A Train

◘ Elevator with $100,000/year Operating Costs

◙ Elevator with $250,000/year Operating Costs

Figure 5.2



Elevator vs. Trucking Costs
Custom and Commercial Trucks
Cost ($) (Times 10E9)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
60
100
140
180
220
260
300
Elevator Spacing Distance (km)
3 Axle with Pup Custom
5 Axle Custom
A Train Custom
A Train Commercial
Elevator with $100,000/year Operating Costs
Elevator with $250,000/year Operating Costs

trucks while not eliminating the larger scale private haulers. It also represents a compromise between the two elevator operating cost scenarios.

5.2.2. Other Location Considerations

The ideal spacing is only one of the factors necessary in determining specific elevator locations. In order to make the location problem more realistic the other conditions must hold as well.

First, the htp elevator should be located at an existing delivery point. This is because infrastructure such as access roads and railway sidings are already in place. Second, the facility should be located on either a railway main line or else a branch line in good repair. In this way the railways are able to abandon some branch lines and concentrate maintenance and capital investment on a high quality network. This decreases transportation costs in the railway sector and contributes to overall system efficiency. Third, htp sites should be located on a primary or secondary highway, preferably at or near the intersection of two or more highways in order to maximize access. Location on a highway is important because, although the trend toward increasingly larger trucks for grain hauling creates an increasing burden on all roads, non-paved ones are especially vulnerable. A final factor is the location of existing htp facilities. Existing htp elevator locations must be used as reference points when determining the location for new facilities in order to maintain the recommended spacing.

5.3. MICRO STUDY

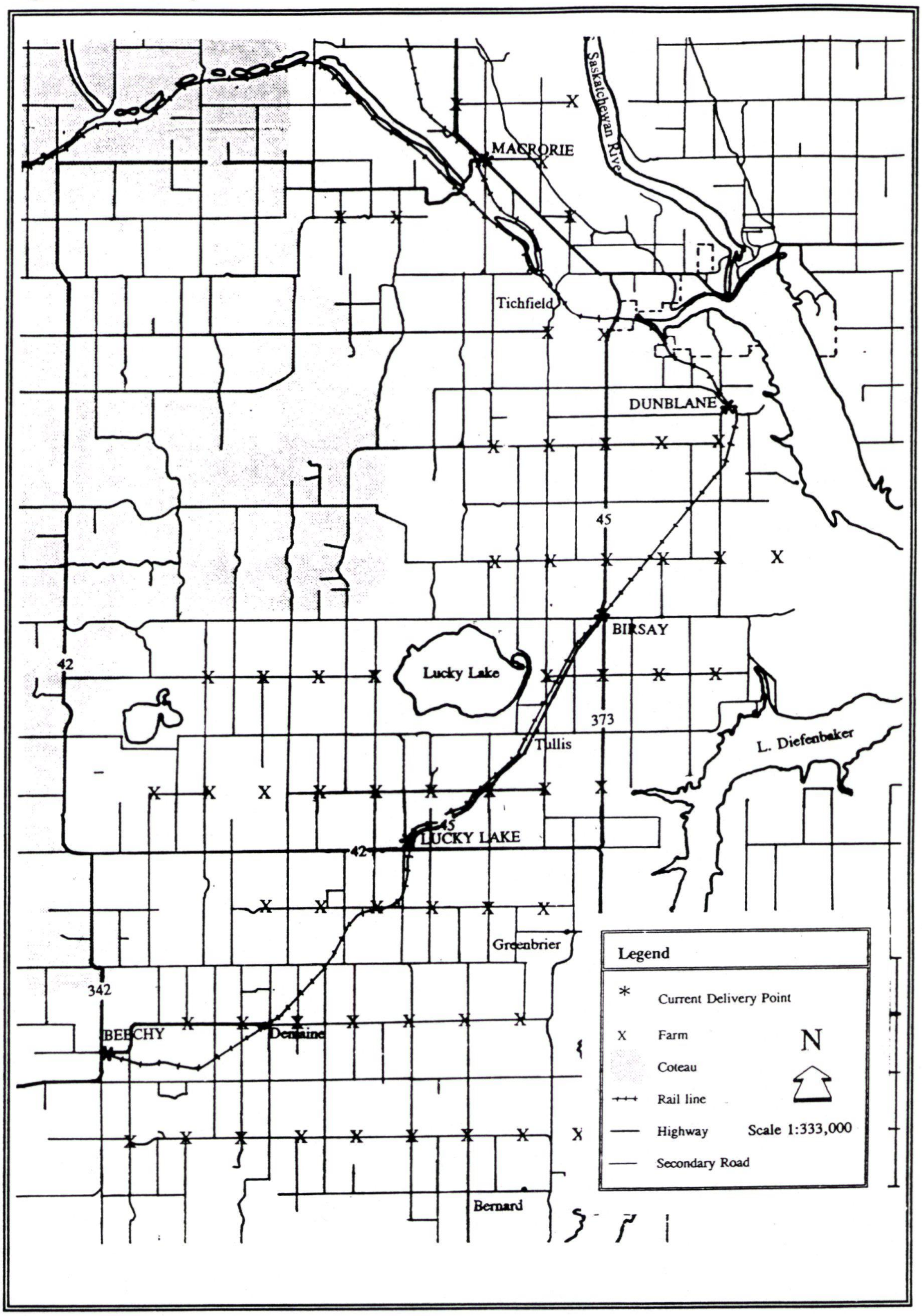
5.3.1. Results

The area shown in Figure 5.3 will be used as the basis of the specific htp location case study. Based on the optimal spacing previously determined, the region should be, but is not, serviced by a htp facility. It is approximately 80 kilometers north/south by 70 kilometers east/west The closest htp facilities are at Rosetown, to the northwest and Eyebrow to the east, across Lake Diefenbaker. Both of these delivery points are approximately 70 kilometers from the center of the study area.

The area includes 212 (aggregated to 53) farms and five existing delivery points: Beechy, Lucky Lake, Birsay, Dunblane and Macrorie, all of which met the location conditions listed in the previous section 5.2.2, describing htp location considerations. It has been selected from among other htp deficit areas because of its relative isolation from the remainder of the grain producing region. Travel to the south and east is almost completely restricted by Lake Diefenbaker and the South Saskatchewan River. In addition, the Coteau, a large grassland area used primarily for grazing surrounds the study area to the west and northwest. These natural barriers aid in the location analysis process because the catchment area for the potential htp elevator is well defined and the system is closed in a theoretical sense.

The warehouse problem software, TSA88 was used to evaluate the five possible sites on the basis of the single criterion, transportation costs. The major weakness of this method is that it allocates farm deliveries to all five delivery points concurrently in order

Figure 5.3: Study Area



to minimize total system costs. It is not designed to use each point separately and then rank them. In order to produce useful output, five separate analyses must be performed. Each analysis uses a different delivery point.

Based on the TSA88 analysis, Birsay and Lucky Lake tie for the optimal htp site with total associated transportation costs of 3.68 million dollars per year each. The value of this analysis, when used in conjunction with DSS, is marginal. Although the delivery points which will result in the lowest total transportation costs are revealed, none of the other concerns surrounding the issue of rationalization are addressed.

In the first DSS evaluation, all seven criteria have been given an equal weighting and aspiration and reservation levels are set to the utopia levels. The specific coefficients associated with the criteria for each of the delivery points are listed in Appendix 1. In this scenario Lucky Lake is selected as the optimal location by all four DSS. The stability of this, and other solutions will be tested in a following section which deals with sensitivity analysis.

Lucky Lake has several characteristics which led to its selection as the optimal location. It is the only alternative with utopia level coefficients for two of the variables, "10M" and "20M" as well as only one of two alternatives with utopia level coefficients for two other variables, "Ship" and "Roadac". Its major weakness is with the "Main" variable for which it ranks fourth among the alternatives.

The second evaluation uses the criteria in a weighted fashion. Recall the weighting is as follows: Ship, 20M and Main 100%; 10M 75%; Farthest and Curcap 50%; Roadac 25%. Under the weighted strategy, the four DSS were not in full agreement. Two of the systems, MATS and DAS, selected Lucky Lake and the other two, DINAS and AIM, selected Birsay. The results are summarized in Table 5.5.

Table 5.5 Comparative Results of DSS

System	Unweighted	Weighted
DINAS	Lucky Lake	Birsay
DAS	Lucky Lake	Lucky Lake
MATS	Lucky Lake	Lucky Lake
AIM	Lucky Lake	Birsay

Birsay does not have as many coefficients as Lucky Lake with utopia values however, it does have advantages over Lucky Lake when the most heavily weighted variables, "Ship", "20M" and "Main", are considered. Birsay shares the lowest total shipping costs (Ship) with Lucky Lake and has only one more producer greater than twenty miles away (20M). Its major advantage is with the "Main" objective. Birsay is 10 miles closer to the main line than Lucky Lake.

The discrepancy in the optimal location selected may be a product of the different methods of weighting among the systems. The weighting for both DAS and MATS is accomplished directly, by specifying a weight for each objective. It is an integral part of the system. DINAS and AIM do not have a built in function to weight criteria.

Weighting is accomplished indirectly by adjusting the aspiration and reservation levels. Once this adjustment is completed, AIM calculates a weighting based on it. The weighting scheme can be displayed so that the user knows the weighting which is being used for the analysis but it is more difficult to pinpoint the exact weight desired. The weighting used, which was as close to the specified weights as could be obtained, was as follows: Ship, 20M and Main 100%; 10M 68%; Farthest 40%; Curcap 25%; Roadac 0%. This was as close to the specifications as it was possible to get. DINAS does not specify how this adjustment affects the criteria's relative importance.

5.3.2. Sensitivity Analysis

Since the TSA88 analysis required a separate run for each delivery point it was not possible to perform sensitivity analysis on these results. The results of the DSS sensitivity analysis from the unweighted situation are shown in Table 5.6. Recall that the DSS analysis involved decreasing the aspiration levels of the objectives one at a time while the other objectives retain aspiration levels equivalent to utopia. The solution appears to be highly stable. With the exception of "Curcap", changes in the aspiration levels of any given criteria do not affect the outcome. The change in optimal location to Birsay, prompted by a change in the "Curcap" variable is of no real consequence. "Curcap" is simply a base line measure of what the pre-rationalization current capacity is, i.e. it is a "snapshot" and as such cannot change.

Table 5.6: Comparative Result of DSS with the Objectives' Aspiration Levels Set Equal to the Nadir Value

Objective	DAS	DINAS	MATS	AIM
Farthest	Lucky L.	Lucky L.	Lucky L.	Lucky L.
10M	Lucky L.	Lucky L.	*	Lucky L.
20M	Lucky L.	Lucky L.	Lucky L	Lucky L.
Main	Lucky L.	Lucky L.	Lucky L.	Lucky L.
Roadac	Lucky L.	Lucky L.	Lucky L.	Lucky L.
Curcap	Lucky L.	**	***	****
Ship	Lucky L.	Lucky L.	Lucky L.	Lucky L.

* When weighted at less than half of the other objectives Birsay is selected, when weighted at between half and equal to the other objectives Lucky Lake is selected

** When the aspiration level is set between the nadir level and 11.9 tonnes Birsay is chosen, when the aspiration level is set between 12 tonnes and the utopia level, Lucky Lake is chosen

*** When weighted at less than half of the other objectives Birsay is selected, when weighted at between half and equal to the other objectives Lucky Lake is selected

**** When the aspiration level is set between the nadir level and 9.4 tonnes Birsay is chosen, when the aspiration level is set between 9.5 tonnes and the utopia level, Lucky Lake is chosen

MATS is the only system with a built in capacity for sensitivity analysis. It indicates the magnitude of change in a specific criteria which is necessary to shift the optimal location. The results of the MATS analysis are listed in Table 5.7. Since MATS selected Lucky Lake in both the weighted and unweighted situations, the sensitivity analysis involved determining the change required to shift the optimal location away from Lucky Lake. With the given utopia and nadir levels, Birsay is the only other alternative which could realistically be considered as a option. The other three alternatives are too inferior. The magnitude of change required in their criteria to displace Lucky Lake is outside of the utopia-nadir range.

Table 5.7: MATS Sensitivity Analysis: Change required in Birsay make it equal to Lucky Lake

	Unweighted	Weighted
Farthest	cannot be made equal	cannot be made equal
10M	change from 23 to 26.8	change from 23 to 29.2
20M	cannot be made equal	cannot be made equal
Main	change from 67 to 59.1	change from 67 to 57.3
Roadac	cannot be made equal	cannot be made equal
Curcap	change from 5.8 to 7.99	change from 5.8 to 11.2
Ship	cannot be made equal	cannot be made equal

No change in four of the seven criteria, "Farthest", "20M", "Roadac", and "Ship", regardless of the magnitude, could shift the optimal location from Lucky Lake to Birsay. This is likely because the coefficients for these criteria for both Lucky Lake and Birsay are already quite close together. Two other co-efficient changes, "Main" and

"Curcap" are moot. Both the current capacity elevator capacity and distance to the railway main line are fixed values, they cannot change by definition. The only co-efficient which has any real chance of changing is "10M", the number of producers within a 10 mile radius of the delivery point. Given that Lucky Lake and Birsay are adjacent points, it is likely that any change in the co-efficient for Birsay will have a somewhat proportional change for Lucky Lake, thus negating the effect. As such, it can be concluded that the solution determined by MATS, with Lucky Lake as the htp elevator site, is highly stable.

5.3.3. Critical Review of Software

This section consists of two major parts. First the TSA88 transshipment linear programming will be compared with DSS software. Second, the four DSS packages used will be critically reviewed. The main factors examined are user-friendliness, flexibility, speed, options available and output. The features of the systems are summarized in Table 5.8.

In many respects DSS are superior to the transhipment problem of linear programming. The transhipment problem seeks a solution based solely on transportation costs. DSS are capable of handling transportation costs as well as many other criteria. As such, DSS allow for a more balanced approach to location analysis. For this particular problem, the locations selected were either Lucky Lake or Birsay, which do share the lowest transportation costs. It would be possible however, to have another problem in another area and/or with a different set of objectives, in which the location selected did not have the lowest transportation costs.

Table 5.8: DSS System Features

	AIM	MATS	DAS	DINAS
Max no. of Objectives	10	40	50	7
Max no. of Alternatives	150	40	60	15
Max no. of Fixed Nodes	N/A	N/A	N/A	100
Max no. of Arcs	N/A	N/A	N/A	~300
Control of Number of Nodes Selected	no	no	no	yes
Cut-off levels	no	yes	yes	no
Direct Weighting	no	yes	yes	no
Sensitivity Analysis	no	yes	no	no

The major problem with DSS is that because, with the exception of DINAS, they are not specifically designed to solve spatial problems and as such cannot perform specifically spatial analysis. The most obvious weakness is their inability to allocate users to specific nodes. This is not a problem with this particular solution as only one node is required, therefore all users will be allocated to it. Problems would be encountered if using DAS, AIM or MATS in a problem where more than one node was required in the solution and users had to be allocated to the nodes however. DINAS is capable of selecting an operator-specified number of nodes but, like the other DSS, does not to specifically allocate users to nodes. TSA88 (warehouse problem of linear programming) does offer the advantage of allocating users to nodes however it does not allow the operator to specify the number of nodes which can be used. This problem has also been identified by Wirasinghe and Waters (1983). A second problem, is the introduction of bias when selecting the objectives to used in an analysis. Several objectives representing the interests of the same group will likely slant the results in favour of that group. This issue is not limited specifically to DSS however, it becomes a factor in all research.

All four DSS systems are relatively user-friendly. DAS offers the advantage of a single interface screen for both on-screen help and data input, modification and analysis. MATS and AIM offer a very straight forward, menu driven system which queries for input, modification and analysis, as well as providing a number of reports. A further advantage to MATS is the provision of graphic representations of the data. The ability to visualize data is being seen as increasingly important in understanding problems. DINAS offers the most complex but sophisticated interface. Unlike the other three systems, it is designed specifically for network based, location problems. It has two interfaces, one for input and the other for analysis. One weakness of the system is that it is not as intuitive as the other three systems.

All four systems are capable of handling problems of a realistic size. Problem size in MATS, AIM, and DAS is controlled by the number of criteria (variables) and alternatives (choices). DAS is capable of solving problems with up to 50 criteria and 60 alternatives (Armada System, 1990, p. 5). AIM can handle problems with 10 objectives i.e. criteria and 150 alternatives (Lofti and Zionts, 1988, p. 1). MATS accepts problems with up to 40 criteria and 40 objectives (Brown et al, 1986, pp. 7-11). DINAS's problem size limitation is based not only on the number of objectives and alternatives but also the number of nodes and arcs in the network. It can solve problems with up to 7 objectives, 15 alternatives (potential nodes), 100 fixed nodes and a few hundred arcs (Ogryczak et al, 1988, p. 2).

The weighting of variables and the inclusion of cut-off, levels is not directly possible with all systems but both options can be achieved either directly or indirectly with all of the systems. It is the most straight forward with DAS and MATS. These systems query directly for weights and cut-off levels. MATS allows the user to either enter the weights directly or it will query the user on the comparative importance of sets of criteria in a pairwise fashion and thereby determine a weighting scheme. AIM and DINAS do not allow for the direct entry of weights or cut-off levels however they can be achieved by adjusting the aspiration, reservation, utopia and nadir levels to place different levels of importance on the criteria. A variable can be given a relatively low weighting by setting its aspiration level close to the nadir level.

DINAS offers several advantages over the three other DSS used. It is the only one of the four which is network based, i.e. that is structured for the input of inherently spatial data. As such, objectives can be associated with either nodes or the arcs connecting them. Because of this, the spatial structure of the network and the potential flows (i.e. routes) within it can be preserved. A second advantage that DINAS offers is that the user can indicate the number of locations which are to be selected, the other packages simply rank the choices. This selection process allows the user to evaluate the difference between one large facility vs. two or more smaller ones. If multiple locations are selected, DINAS allocates users to facilities. Because of this, DINAS is the only viable DSS in multiple facility location problems in which allocation is required.

A possible disadvantage to the DINAS system is the inability to weight the objectives or perform a sensitivity analysis directly. It has been demonstrated earlier in this paper however that weighting can be accomplished indirectly by adjusting the reservation and aspiration levels.

Although only seven criteria (objectives) may be active in DINAS at one time the system can store more. The advantage to this is that a large number of objectives can be entered and the problem can be run activating different combinations of them. The sensitivity of the solution can also be checked by disabling an objective temporarily and re-running the problem to test whether or not the same solution is produced. If the solution does not change it can be assumed that that particular objective is not a major influence on the location selection for the given problem. Conversely, if the optimal location does shift it can be concluded that that criterion is an important discriminator between potential sites for the given problem.

5.4. Summary

It has been concluded that the optimal spacing for htp on a Saskatchewan-wide basis is between 40 and 60 kilometers. This is based on the equilibrium cost point between trucking and elevator costs. The spacing favours custom and commercial haulers because the trend in grain transportation is toward these larger scale, more cost-effective haulers.

Based on this optimal spacing, a htp-deficient region in south-west Saskatchewan was identified. The five existing delivery points within the study area were evaluated by both the warehouse problem of linear programming and DSS to determine the optimal site for a htp facility within the region. The DSS used seven criteria in the evaluation. While all four systems did not fully concur on the most satisficing solution, it has been concluded that Lucky Lake would be the optimal site for an htp facility. It was selected unanimously by all systems when the criteria were equally weighted and by the two systems which allowed for controlled weighting in the weighted situation. Theoretically, the optimal site could be shifted to Birsay if the coefficients for certain criteria changed although realistically, this is not likely to occur.

CHAPTER 6

SUMMARY AND CONCLUSIONS

In brief, the thesis has established a framework for analyzing the htp facility location aspect of the grain handling and transportation system. The analysis involved two major steps. First the optimal spacing distance between htp elevators in Saskatchewan was established. Second, one specific facility was located within an htp-deficit area. The optimal spacing was determined by trading off the capital operating cost of an htp elevator network with the cost of trucking grain to elevator. Elevator costs favour a widely spaced network whereas trucking costs favour a more dense one. Once the optimal spacing was determined and an htp-deficit region determined, DSS were used to locate an htp elevator within the area.

The spacing distance associated with the equilibrium cost point varied between 30 and 70 kilometers, depending on the truck type and elevator operating cost scenario used. It has been concluded however that the optimal spacing for facilities is in the range of 40 to 60 kilometers apart. This spacing range represents a compromise between the various cost scenarios, while also reflecting the trend toward larger scale trucking. That is not to say that htp elevators should be located in a perfectly symmetrical pattern across the grain growing region of the province. Rather, the spacing should act as a guide for selecting locations and identifying htp-deficit areas. A number of other factors are also requisite for an htp elevator site. These include: being at an existing delivery point, on a high quality road and an active railway branch line with the ability to generate a relatively large volume of traffic.

Based on the spacing suggested by the first part of the study, an htp-deficit area in south western Saskatchewan was identified. The area contained 53 farms (which were actually the aggregation of a total of 212 farms) and five existing delivery points located along a single branch line. The problem was first optimized using the so called warehouse problem of linear programming. This approach, which optimizes solely on the basis of transportation costs, selected either Birsay or Lucky Lake as the optimal site. Locating the elevator at either of these two sites results in the same total cost, which is lower than the shipping costs associated with the other three delivery points. The four DSS, which used a total of seven different criteria concurrently in the analysis, also selected either Lucky Lake or Birsay. Lucky Lake was always selected when the criteria were weighted equally. When the criteria were weighted the results were split between Lucky Lake and Birsay. Because of the subjectivity of the weighting procedure the author has more confidence in the Lucky Lake solution. The selection of either point would offer the opportunity for a portion of the railway branch line to be abandoned.

Because DSS is essentially a quantitative tool, i.e. it uses quantitative input, specific values for each objective can be determined in the final solution. As such, if for the benefit of the greater majority, some individuals or groups are greatly disadvantaged by a DSS selection, the magnitude of this can be measured. In the particular case study used in this thesis, Lucky Lake has been deemed as the most satisficing site for an htp elevator. Although Lucky Lake is the best compromise site in an overall sense, it may not be an acceptable location from the perspective of some individual producers. Producers who are located greater than an exogenously determined reasonable hauling distance, such as the 25-30 miles suggested by the Transportation Talks workshops (1992, p. 14), may be considered for compensation because they are directly disadvantaged for the greater benefit of the system as a whole.

The solution produced by the DSS is not an absolute. It is influenced in the formulation stage by the objectives used and by the weightings given to each objective. Despite these weaknesses however, DSS is an effective tool for addressing this complex problem because it seeks the best compromise from amongst a conflicting set of interests and objectives. Although it is not likely that any given group will be fully satisfied with the solution produced, hopefully the groups will find the solution satisficing and understand that it represents the best compromise. Through the use of DSS, a more balanced and realistic approach may be possible than with the more traditional, single criterion models. Numerous conflicting objectives representing the interests of a broad range of players can be included. As well, both equity-based and efficiency-based objectives can be included in the same analysis. This flexibility is important because the issue is not simply economic. The political factors are at least as important, if not more so than the economic ones.

DSS offer great promise in the field of spatial analysis. This will be enhanced further by work currently being carried out to develop spatial decision support systems (SDSS) (Densham and Rushton, 1987). SDSS can offer the DSS features of concurrent, multiple criteria analysis, along with spatial-specific features such as allocation capability and visual display.

The use of DSS also complements current research in the area of group decision making and the social movement toward empowerment. It allows a wide range of players to participate in the decision making process by formulating their own objectives. As such it has the potential to address complex issues without alienating or dismissing the various affected parties.

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APPENDIX 1: Co-efficients for DSS Criteria

	Beechy	Birsay	Dunblane	Lucky Lake	Macrorie
Farthest	49	30	42	31	48
10M	13	23	14	30	8
20M	24	8	25	7	34
Main	91	67	57	77	45
Roadac	90	100	80	95	100
Curcap	15.4	5.8	2.6	10.1	3.1
Ship	4.6×10^8	3.7×10^8	4.2×10^8	3.7×10^8	4.7×10^8