Facility Planning for Large Equine Facilities in the Pacific Northwest

by
Aimee Glenn

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Industrial Engineering (Honors Scholar)
Honors Baccalaureate of Arts in International Studies (Honors Scholar)

Presented December 15, 2014
Commencement June 2015

AN ABSTRACT OF THE THESIS OF

Aimee Glenn for the degree of Honors Baccalaureate of Science in Industrial Engineering and Honors Baccalaureate of Arts in International Studies presented on December 15, 2014. Title: Facility Layout Planning for Large Equine Facilities in the Pacific Northwest.

Abstract approved:

Hector A. Vergara

Large equine facilities are comprised of many different departments (areas) that are necessary for the proper care and maintenance of horses. The placement of departments is often inefficient due to the slow growth of equine facilities. As a result, facility layout becomes a crucial aspect requiring explicit consideration because mandatory daily tasks (e.g. feeding and waste management) often involve large amounts of time wasted handling materials and livestock while the tasks themselves take little time to complete. The purpose of this study was to develop an analytical method which can be applied to large equine facilities within multiple cultures to produce efficient layouts that are simple and economic to implement. This research developed, implemented, and tested an optimization algorithm that can be applied to the equine facility layout problem to minimize the distance travelled by facility personnel performing daily operations to reduce the total distance travelled for mandatory tasks. The proposed algorithm was applied to two test cases based on equine facilities located in the Willamette Valley and on the Umatilla Indian Reservation improving their initial, annual layouts by 7% and 6%, respectively. Material flows and distances vary greatly between these cases, yet the proposed algorithm proved effective on both.

Key Words: equine facilities, facility layout, algorithm, optimization

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

Aimee Glenn, Author

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1 INTRODUCTION

1.1 Background and Motivation

In the United States, there exists a large population of horse owners who can be categorized into two groups: those who own horses as companion animals, and those whose livelihoods depend on their horses or livestock. Those who use horses as companion animals often rent spaces at designated equine boarding facilities to house their equine friends. Those who own horses as part of their livelihood generally house their horses on their own property, and will occasionally rent out part of their facility to other horse owners, such as those who belong to the companion animal group. These facilities are used for more than just the housing of the horses and include, but are not limited to: feed storage, grazing pastures, storage and removal of waste, appropriate spaces for the grooming, washing, exercising, and training of the horses, storage for the equipment associated with the previously mentioned activities, and space for storage of trailers. The placement of these important components within the facilities are often illogical due to the natural slow growth of these facilities which makes their use inefficient. Simple tasks, such as cleaning stalls and feeding horses, often involve large amounts of time wasted while handling and moving materials and livestock while the actual tasks themselves take very little time to complete. Often, only one primary caretaker will care for all the livestock in the facility and these two tasks alone—cleaning stalls and feeding horses—can require an entire 8-hour workday. This represents an excessive waste of time when the majority of those eight hours are spent transporting materials. This time commitment to daily care and maintenance is mostly relevant in large equine facilities, which are defined as any equine facility housing at least 25 horses.

1.2 Thesis Statement

The purpose of this thesis was to identify a general analytical methodology to develop efficient facility layout plans for large equine facilities which can be applied to existing and future facilities within multiple cultures in the Pacific Northwest. As part of this thesis, we developed a general methodology based on facility planning theory to improve existing layouts of large equine facilities focusing on maximizing the efficiency of daily operations. This methodology was applied to two different test cases within the Pacific Northwest. Case 1 and Case 2 correspond to existing facilities located in Benton County and on the Umatilla Indian Reservation in Eastern Oregon, respectively. Case 1 is representative of typical equine facilities in the Willamette Valley. Case 2 was evaluated using seasonal flows for the periods of summer, winter, and an annual average.

1.3 Expected Contributions

After completing this thesis, the expected contributions are:

- Provides a facility planning resource to local facility owners.
- Considers cultural differences within the Native American community which affect equine facility layouts.
- Provides a simple and economic method to assist in the reduction of distance travelled on a daily basis by facility personnel.

- Opens the door for application of traditional industrial engineering principles to other types of livestock facilities.

The remainder of this document is organized as follows. Section 2 presents a literature review of relevant facility planning and layout theory that was studied to develop the proposed methodology. Section 3 describes the steps of the developed method along with the necessary inputs for its application. Section 4 presents the results of the two test cases on which the proposed method was applied. Section 5 compares the two test cases evaluated and discusses the application and relevance of this study in addition to nuances of the developed method. Section 6 presents the conclusions of this study and future work.

2 LITERATURE REVIEW

2.1 Existing Literature Pertaining to Equine Facilities

Facility planning for large equine facilities has not traditionally been a focus of most literature dealing with the setup of these facilities on both small and large scales. In general, the available literature pertaining to equine facilities focus on what types of materials and layouts work best for certain types of horses and specific types of facilities rather than the effect these layouts will have on those caring for the livestock. The methods recommended are general and more akin to "common sense" approaches (i.e., not optimal) since they are methods which work well and have been tested and modified through many years of experience. To the best of our knowledge, no mention of times to complete tasks or other considerations for the caretakers is made in the existing literature as emphasis is placed solely on the health and well-being of the horses. While it is very important to put the needs of the animal first, it is also important to know how much time the relative location of certain departments will add to mandatory tasks since more time means additional money committed to the operation of the facility.

The existing case studies and other publications have thoroughly outlined the requirements of large equine facilities and noting which components of the facilities are absolutely necessary. The following is a list of necessary facility components (also referred to as *departments*) outlined by Hill (1990):

- Barn(s) with stalls
- Runs, pens, paddocks, pastures
- Storage for feed, bedding, machinery, tack, and other equipment
- Training areas: grooming area, wash rack, shoeing and vet area, breeding shed, laboratory, office, tack room
- Driveways, walkways, parking areas
- Shelter belts, wind breaks, wildlife areas
- Water and other utilities

This list of departments is comprehensive, but not all facilities will require each of these departments, and some may require more specific components depending on the type of facility. At a minimum, the four principal departments which must exist at any large equine facility are: shelter for horses, provision of feed and water, areas for exercise, and a system for management of waste (i.e., storage of bedding and manure). Existing literature does not provide any guidelines for the placement of these four departments and no previous research found has attempted to answer this question.

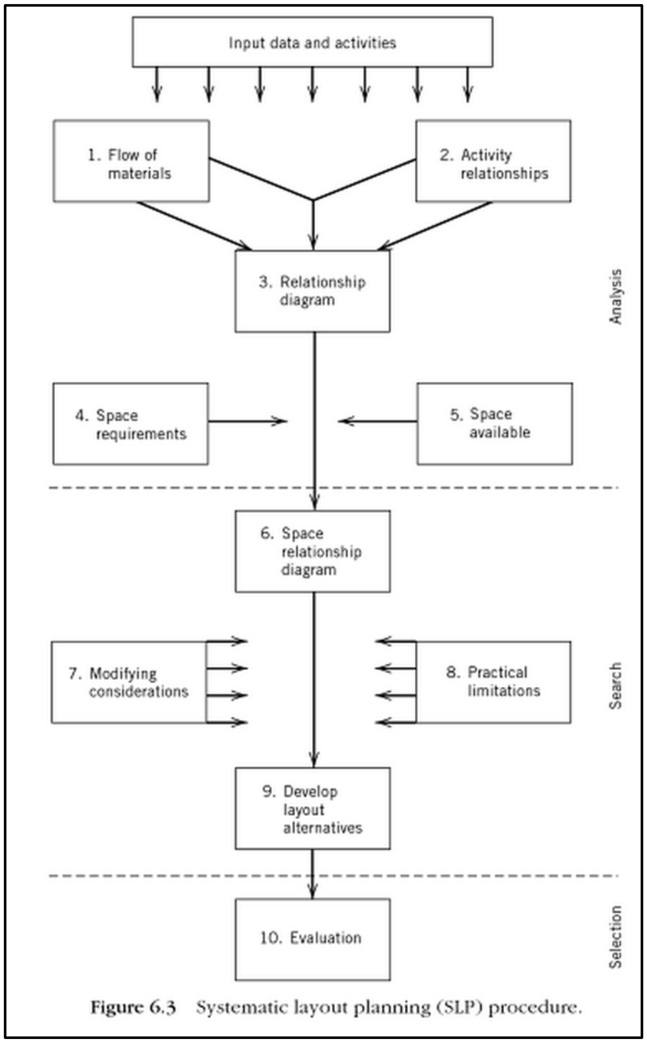
2.2 Facility Layout Planning Procedures

In order to focus more on the layout aspect of these facilities while still taking into account the needs of the horse, several facility layout methodologies have been considered for application. Layout procedures can generally be split into two procedure types: construction and improvement. Construction layout procedures focus on developing a layout from scratch with the intent to build a new facility, while improvement layout procedures begin with an initial layout and make changes to improve the current facility (Tompkins et al., 2010).

2.2.1 Construction Layout Procedures

Apple (1977) and Reed (1961) were pioneers in the realm of layout procedures. They proposed several action steps which should be completed in order to create layouts which are well-designed for their specific applications. These action steps include tasks such as collecting data, speaking with necessary higher-ups, determining mandatory requirements and constraints, considering different aspects of the process, and constructing and evaluating layouts. While these steps pointed facility planners in the correct direction, they do not provide a direct road map to layout planning success and do not suggest specific quantitative and qualitative tools that can be used in the design and optimization processes.

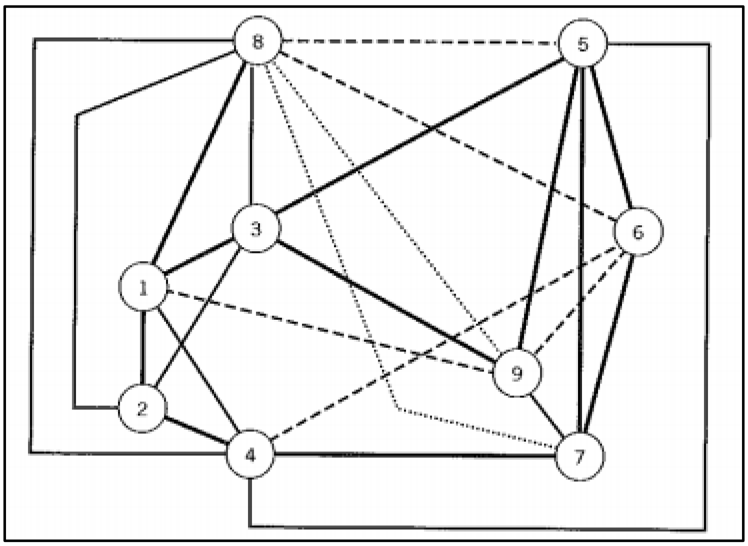
Muther (1973) developed a construction layout procedure called Systematic Layout Planning (SLP) which outlines specific steps to analyze processes, develop relationships, generate alternative layouts, and evaluate the layouts based on some criteria. Figure 1 shows a flowchart of the steps required in SLP.



Source: Tompkins et al., 2010

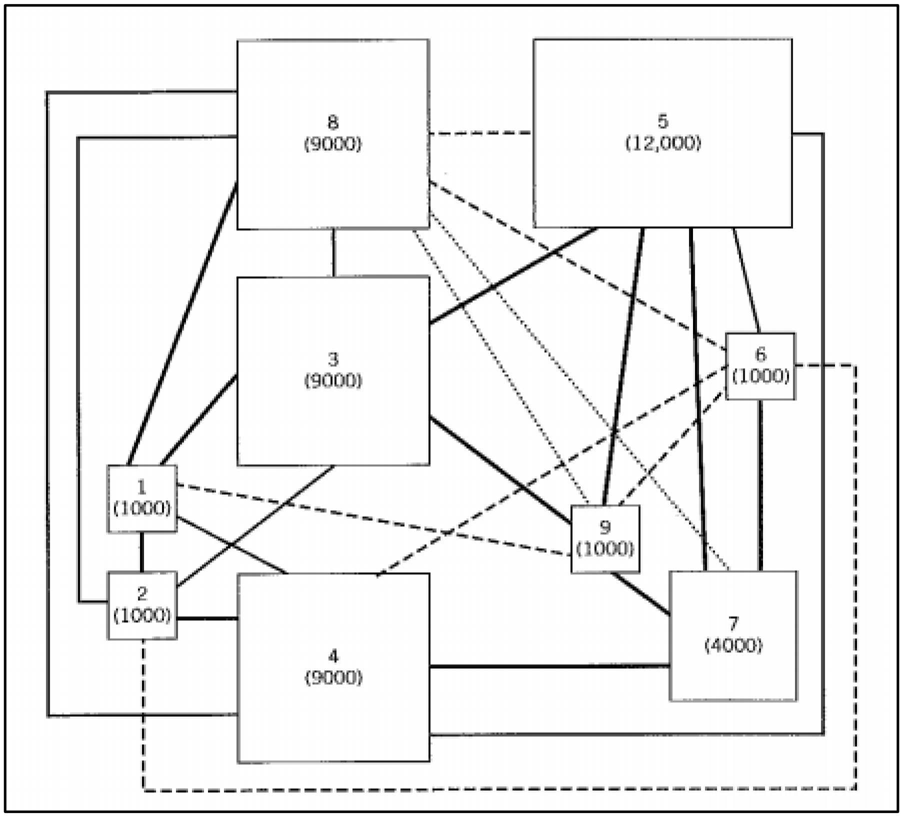
Figure 1: Systematic Layout Planning (SLP) Procedure

SLP begins with the creation of relationships between activities, which can be accomplished in many ways. Several common methods for developing and quantifying these relationships exist, including activity relationship charts and from-to charts. Once relationships have been identified and quantified, a relationship diagram is created. A relationship diagram is a network of departments (nodes) and lines which represent the strength of the relationship between the departments (Figure 2). Next, a space relationship diagram is developed which transforms the department nodes into boxes which represent a scaled version of the department's actual area (Figure 3). From this diagram, alternative block layouts (Figure 4) are made while trying to maintain each department's relational requirements. These block layouts are then evaluated against the original criteria.



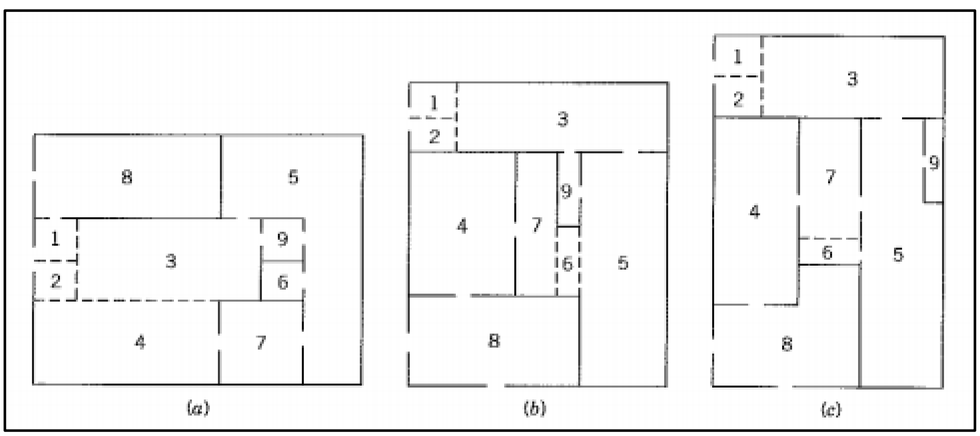
Source: Tompkins et al., 2010

Figure 2: Relationship Diagram



Source: Tompkins et al., 2010

Figure 3: Space Relationship Diagram



Source: Tompkins et al., 2010

Figure 4: Alternative Block Layouts

2.2.2 Computerized Layout Procedures

The SLP method has proven to be a useful heuristic in facility layout planning, but it requires a significant amount of time to manually generate the block layouts and does not guarantee an optimal solution. Alternatively, another methodology used for layout planning considers mathematical algorithms. These algorithms still only serve to assist the facility planner in making decisions and further manipulating layouts, but much of the labor intensive work can be reduced by these mathematical algorithms which can be evaluated by computers. In order to evaluate and compare layouts generated, it is necessary to quantify the "fitness" of a layout. The two most common performance measures use distance and adjacency based scores. Material handling problems generally try to minimize the distance scores and others attempt to maximize the adjacency score. Facilities which are evaluated using a distance based objective are typically more suited for from-to chart inputs whereas adjacency-based objectives often use relationship charts, although either input can be modified to mimic the other as necessary (Tompkins et al., 2010).

One of the earliest mathematical algorithms developed was the *Computerized Relative Allocation of Facilities Technique* or CRAFT (Tompkins et al., 2010). CRAFT is an improvement algorithm which uses a modified pairwise exchange method to minimize a distance-based objective function. While a general pairwise exchange method can be evaluated using both adjacency and distance-based objectives, CRAFT uses only a distance-based objective. To evaluate this objective function, CRAFT requires a from-to chart of the flows between departments and a distance matrix based on an existing layout.

In a traditional pairwise exchange method, once the original objective function is calculated, all feasible department pair exchanges are performed and their respective objective functions are calculated. From the list of new objective functions, the pairwise exchange with the lowest objective value is selected and implemented only if it is better than the current layout. Other iterations of this procedure are completed until no single pair-wise exchange provides an objective function value that is better than the current one. Choosing to implement the lowest value objective function from one iteration is known as the “steepest descent” method, since it moves the solution in the direction of the largest improvement. Limitations of the pairwise exchange method include original layout bias, meaning that a different original layout will often yield a different final layout. This method also does not guarantee an optimal solution because it can get stuck at local optima and has no way to move beyond them.

CRAFT uses a modified pairwise exchange method where only departments which are adjacent or of equal area may be exchanged rather than all departments in the traditional pair-wise exchange method. This would potentially reduce the time to obtain a solution and will result in a layout that might be more applicable in practice. The stipulation that exchangeable departments must be either adjacent or of equal area is significant because CRAFT is one of the first mathematical algorithms addressing the issue of departments with different areas.

Another computerized method for facility layout was created by Tam (1991) which is called *Layout Optimization with Guillotine Induced Cuts* (LOGIC) method. This method also requires a from-to chart of the flows between departments, the area of the entire facility, and the areas of the individual departments as inputs. LOGIC uses a distance based objective to evaluate layouts and it was originally developed to be used as a construction type layout tool, but it can be modified to be used as an improvement type method. In the first step of this method, a list of department names is "cut" and the departments are allocated to the east or west of the facility if a vertical cut was made or to the north or south if a horizontal cut was made. The "slicing" process is repeated using a pseudorandom search until all departments have been "cut out" and each have their own section of the facility with their specified areas. LOGIC is able to exchange departments with unequal areas but has trouble with fixed departments or departments and facilities with specific non-rectangular shapes.

More recent studies explore the use of genetic algorithms applied to the facility layout problem. Genetic algorithms were developed by Hollande (1975) and revolve around the "survival of the fittest" principle which mimics the evolution of genes in populations as they grow and mutate. An initial "family" of solutions is used as the base population from which future "generations" of solutions are created. Two random parent solutions from the original population are selected and mated to create two offspring. This process is repeated until a new population of solutions has been created. New generations are created continuously until a certain number of iterations have been completed or the mean objective function remains approximately the same without improvement. Each genetic algorithm has a different set of rules or parameters which dictates how offspring are created and whether or not mutations or elitist survival occurs. The "genes" are simply coded solutions which point to different layouts. Perhaps the most important aspects of genetic algorithms are the large pools of solutions generated and their ability to move away from local optima to lesser solutions in order to find better ultimate solutions. This feature is what prevents genetic algorithms from the "initial layout bias" many other methods are susceptible to, such as SLP.

Genetic algorithms are often combined with other methods to make them applicable to the facility layout problem. For example, LAYAGEN is a method used by Pérez et al. (2004) to optimize facility layouts of milk goat livestock farms in Spain. This method is a combination of SLP, slicing tree cuts and genetic algorithms.

In another study, Kulturel-Konak and Konak (2013) developed a linear programming and genetic algorithm hybrid approach for the facility layout problem dealing with unequal areas. Their approach aimed to offer an alternative method for solving unequal area facility layout problems, which are difficult to solve using available mixed integer programs due to their complexity, and adds the crucial ability to move away from local optima where mixed integer problems often end.

Also, El-Baz (2004) used a genetic algorithm to minimize the material handling cost resulting from material transport between machines within a facility. This modular approach is more akin to the assignment of departments within equine facilities, since they are often not adjacent.

Li and Love (1998) applied genetic algorithms to construction site layouts with many different non-adjacent facilities placed on one construction site. Their method attempted to minimize the total distance between facilities in order to optimize material handling. The straightforward approach and gene-coding used is very appealing in its simplicity and ability to be applied readily with only a from-to chart and facility and site area data. The main flaw with Li and Love (1998)'s study is that it assumes each area designated for a department can accept any of the departments, including the largest and the smallest departments, despite the size disparity. This assumption is what allows the genetic algorithm portion of the method to provide viable solutions. This method would work well in areas without space restrictions where new facilities are being built. Due to these restraints, it would be difficult to adapt Li and Love (1998)'s method to an improvement methodology when space is often limited.

2.3 Conclusion Regarding Existing Facility Layout Planning Procedures

While many facility layout planning methods exists, none were found that were applied directly to equine facilities. In addition, no methods were found that could easily be adapted to the equine facility layout problem due to the unique nature of both the type of facility and the specific characteristics of the methods currently available. However, a method based on exchanging departments and evaluating quantitative criteria can be developed to address the facility planning problem for large equine facilities as described in Section 3.

3 METHODOLOGY

Due to the natural slow growth of most equine facilities, they are often organized inefficiently and daily mandatory tasks are much more time consuming than necessary. This thesis strives to reduce the amount of time spent performing daily tasks through improving the facility's layout. The method developed to address this problem is an improvement type algorithm which rearranges the departments within the facility to optimize material and livestock handling by minimizing a distance-based objective function in order to minimize the distance travelled by employees performing daily operations.

The rest of this section explains the steps which need to be completed to implement the method and developed algorithm. Section 3.1 illustrates how to represent the facility or site in question. Section 3.2 lists the data to be collected for the method. Section 3.3 explains the improvement algorithm in detail. Section 3.4 emphasizes the need for layout analysis, and Section 3.5 describes the implementation of the method. Figure 5 provides a high-level outline of the proposed method for improving the layout of large equine facilities.

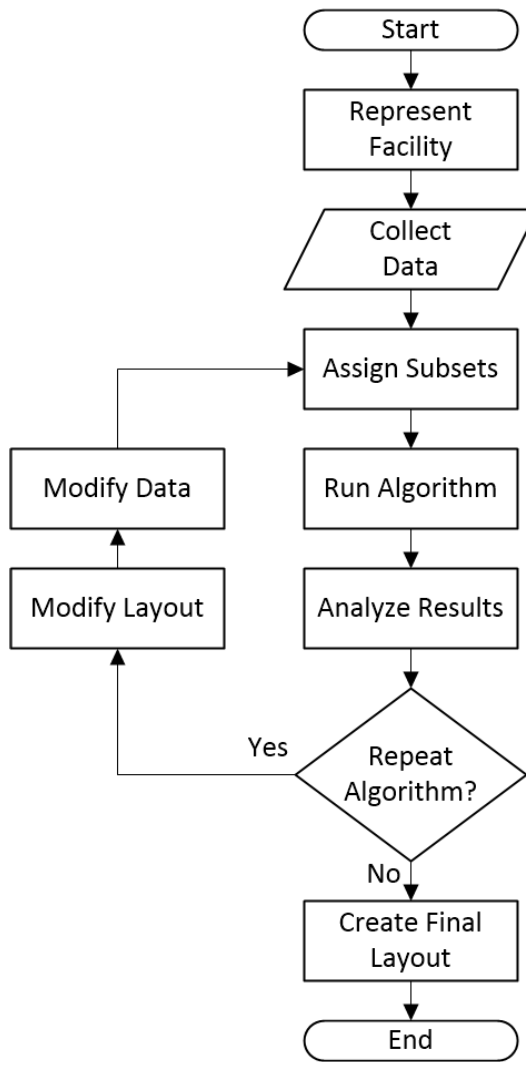
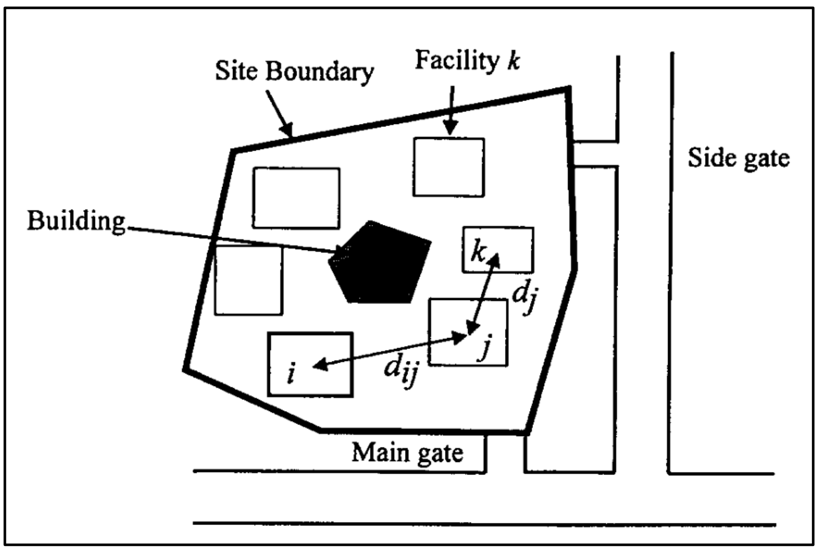


Figure 5: Solution Method Procedure

3.1 Facility/Site Representation

The first step in the methodology to develop an improved layout for a large equine facility is to represent the facility or site in a block layout style with clearly labeled departments. The paths between departments should be known although it is not necessary to show them in the block layout. However, if there are any permanent path restrictions which must be navigated around, these should be noted on the layout. Figure 6 shows an appropriate block layout for a site in a different context (Li and Love, 1998).



Source: Li and Love (1998)

Figure 6: Block Style Representation of a Site-level Facility Layout

3.2 Data Collection

In order to apply the proposed method, a distance matrix and a from-to chart with the flows between departments in the facility must be provided. The distance matrix provides the distances between the departments. Distances should be measured between the centroids, or the centers, of departments using rectilinear paths. Rectilinear paths contain only straight lines and right angles; even if the physical path is curved, the rectilinear distance is a good approximation of the actual distance between two departments at the facility site level. If there is more than one possible path between two departments, the shorter of the two distances should be used in the distance matrix. On the other hand, a from-to chart contains flow information between each pair of departments to characterize the relationships between the departments within the facility. This study assumes that only the mandatory flows necessary for the daily operations of the facility will be considered and that the flows are representative of the average flows throughout the year. Figure 7 shows a distance matrix and Figure 8 gives an example of a from-to chart.

Distance Matrix

	A	B	C	D	E	F
A	--	15	40	65	70	30
B		--	80	10	25	75
C			--	25	55	45
D				--	60	5
E					--	35
F						--

Figure 7: Distance Matrix

From-to Chart

	A	B	C	D	E	F
A	--	8		2		7
B	1	--				
C			--		4	
D		5		--		1
E	3			4	--	2
F			6			--

Figure 8: From-to Chart

3.3 Improvement Algorithm

The goal of this algorithm is to minimize the overall distance travelled by employees in order to optimize material and livestock handling at the facility. The total distance travelled by employees is represented by the number of trips made to each department (from-to chart) multiplied by the distance between the departments (distance matrix). To reduce the overall distance (objective function), the algorithm considers exchanging the location of departments within a subset containing those departments that are feasible to be exchanged. The exchanges result in different distances between certain departments. If the exchange reduces the distance between departments which are visited often, the overall distance will decrease. If this occurs, the exchange is implemented. If an exchange does not reduce the overall distance, it is not used. The algorithm continues switching departments and implementing exchanges that improve the objective function until it can no longer find an exchange which reduces the overall distance.

3.3.1 Creation of Subsets

It is up to the user to group the departments into different subsets. During this process it is important to take into account the feasibility of an exchange (i.e., whether this exchange would be possible in reality), and the areas of the departments being exchanged. When two departments are exchanged, the algorithm assumes that the centroids of the departments are exchanged and they will occupy the same space as the previous department in that location. The nature of the exchange makes the area an important consideration in subset development because it allows larger departments to be exchanged with smaller ones. It is up to the user to group departments in such a way that these unequal area exchanges remain feasible. Subsets also determine whether or not a department is permanent, or fixed. If a department is fixed, it should not be included in any of the subsets and will therefore not be considered for exchange.

3.3.2 Algorithm

The improvement algorithm can be summarized as follows:

Step 1: Collect flow and distance data from existing facility.

Step 2: Organize the departments into subsets.

Step 3: Calculate the objective function (z) of the existing facility.

$$z = \sum_{i=1}^{N} \sum_{j=1}^{N} f_{ij} d_{ij}$$

Step 4: Exchange departments within each subset and evaluate the objective function of each exchange.

Step 5: For every exchange that produces a lower objective function, implement the exchange immediately and continue evaluating department exchanges within the subsets using the updated layout.

Step 6: After the exchanges within all subsets have been evaluated, one iteration of the algorithm has been completed. Note the final objective function of the iteration and initiate another iteration by returning to Step 4.

Step 7: Stop the algorithm after an entire iteration produces no improvement in the objective function.

The flow chart in Figure 9 explains the developed algorithm in detail.

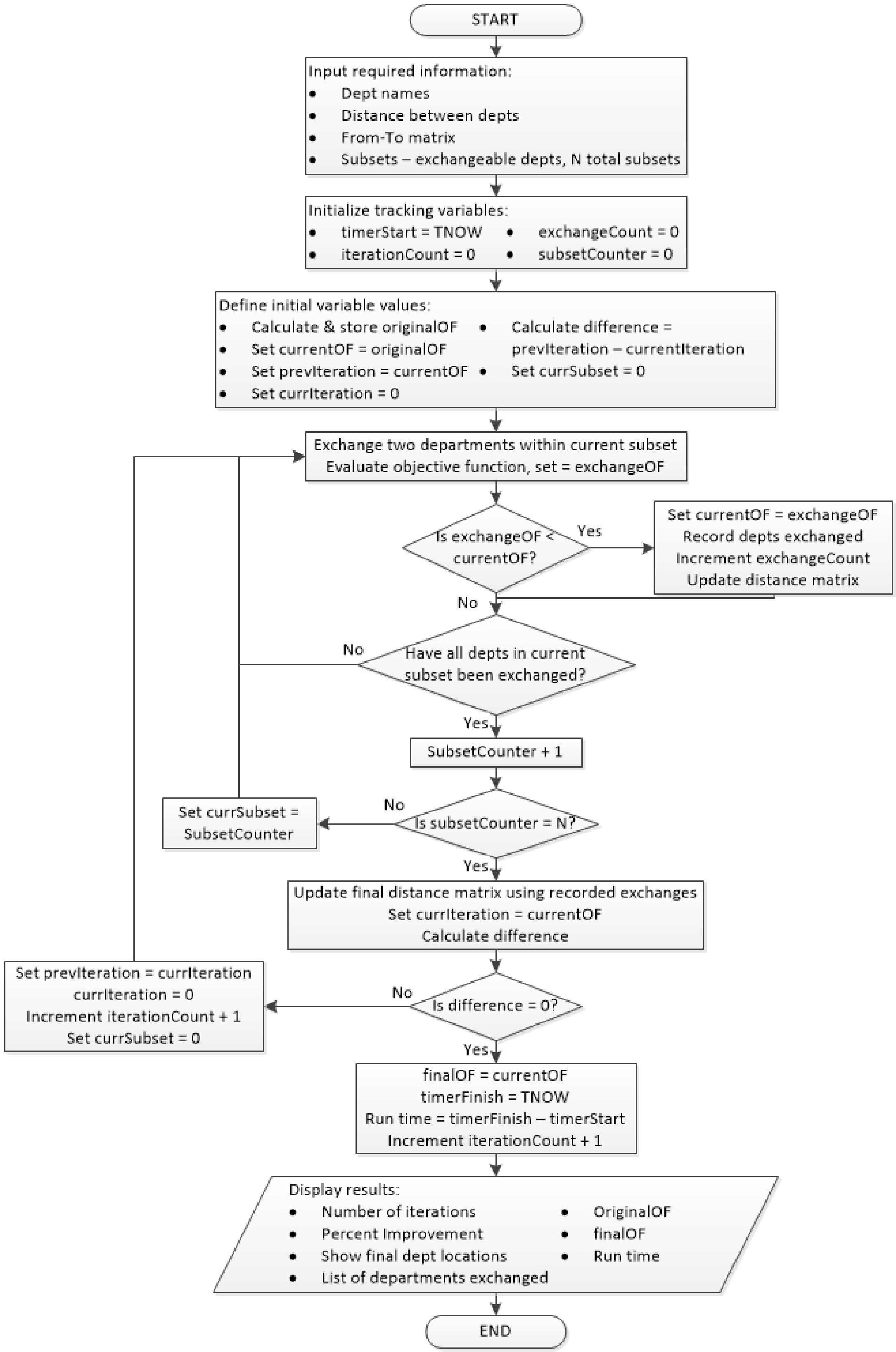


Figure 9: Layout Improvement Algorithm Flow Chart

3.3.3 Performance Measures

The performance of the proposed improvement algorithm can be measured by two performance metrics: the number of iterations evaluated, and the run time of the algorithm. The higher number of iterations and the longer the run time indicates that finding an optimal solution was more difficult.

In addition, one of the outputs of the proposed algorithm is the overall percent improvement of the layout and the percent improvement of each implemented exchange. These measures show how the improvement from each exchange builds on the exchange implemented before it and that all of these exchanges must be implemented to realize the total percent improvement of the facility. The overall percent improvement of the layout can help the user to determine whether or not the suggested improvements will be worth the cost of implementing them.

3.4 Layout Analysis

The final layout produced by the algorithm needs to be analyzed for feasibility and may need to be adjusted. Since the algorithm assumes the centroids of the departments are exchanged, this may produce layouts which contain overlapping or unnecessarily distant departments if a large department is exchanged with a significantly smaller one. The layout can then be modified and the departments relocated to more practical locations. If desired, the distance matrix can be modified to fit this new and improved layout and the algorithm can be run again to determine the new objective function value and test for further improvements.

3.5 Implementation of the Method

3.5.1 Computer Implementation

The proposed algorithm presented in Section 3.3 was implemented using Visual Basic for Applications (VBA) on Microsoft Excel 2013. The user is required to input all data (i.e., departments, distance matrix and from-to charts) using Excel spreadsheets.

3.5.2 Test Cases

Two test cases were developed to test the developed algorithm. Test Case 1 was based off of a local equine boarding facility located in Benton County which predominantly houses horses as companion animals. Test Case 2 was based off of a large equine facility on the Umatilla Indian Reservation in Eastern Oregon which is solely used for livestock production and training and is the owner's livelihood. The details of these cases and their outcomes can be found in Section 4.

4 RESULTS

Two cases were developed to test the layout optimization algorithm. Case 1 is based on a local equine boarding facility in Benton County. The facility houses between 25 and 35 horses year round and is predominantly used by companion animal horses and their owners, although some breeding and training is present as well. Case 1 is meant to be representative of boarding facilities in the Willamette Valley area.

Case 2 is based on a facility on the Umatilla Indian Reservation in Eastern Oregon. The facility uses approximately 48 acres of land and houses between 50 and 65 horses year-round. This facility is used for the breeding, training, and sale of racehorses. Case 2 is meant to be representative of large equine facilities on Native American reservations in the Pacific Northwest which are the livelihoods of the owners.

Both cases were evaluated using average, annual flows in order for the optimization algorithm to produce a layout that would be beneficial year-round. In addition to the annual approach, Case 2 was evaluated during the summer and winter periods. The flows at the facility in Case 2 change significantly depending on the time of year; these two periods were considered to gauge how much the different flows affected the overall distance travelled at the facility.

4.1 Facility Representation and Subset Determination

While both of these cases were tested using the same layout improvement algorithm, it should be noted that several different approaches can be taken with respect to both the representation of the facilities and choice of subsets. When representing the facility, it is possible to include “buildable space” which manifests as non-existent departments where the owner is willing to build. It may also be practical to split up large departments into smaller ones for exchange with other departments of smaller area, i.e. splitting a large pasture up into several smaller pastures and exchanging those pastures (departments) individually.

With respect to subsets, department area and feasibility of exchange are two key components, but so is the overall distribution of subsets. It is possible to include all departments within a single subset to initiate a complete pairwise exchange amongst all departments, but this approach will often produce infeasible department exchanges and result in several iterations needed in order to yield realistic solutions. To evaluate the two test cases presented in this study, departments of similar areas were selected for the same subset. If a department's area is close to the areas of departments in two separate subsets, it can be included in both subsets which will allow it to be exchanged with as many feasible departments as possible.

The way the optimization algorithm makes exchanges is heavily dependent on how the department flows are represented. For example, no exchanges involving pastures were sustained. This is because the flows from other departments, such as feed storage or water supplies, to the pastures were all made to be identical. The reason for this is that when the flows represented current feeding practices, such as only sending alfalfa hay to one pasture and none of the others, the algorithm would move the pasture receiving alfalfa hay to a location that is close to the Alfalfa Shed. While this exchange does shorten the required distance, it is a reflection that management practices should be altered rather than the actual layout of the facility. If it is more difficult to access one pasture than another, and thus more beneficial to employees to have feed storage closer, it would be necessary to fix the pasture by excluding it from the subsets and increasing the flow level to that pasture to emphasize the extra time it takes to access.

4.2 Results for Case 1

Case 1 is a large facility with limited amount of space. Figure 10 depicts the original facility with all physical boundaries. Since Case 1 is based on a boarding facility with highly variable flows due to owners coming and going as they please, only the activity for mandatory daily tasks and operations performed by employees, e.g. feeding all horses and cleaning stalls, were considered in the flow data in the from-to chart. See Appendix A for the department key, distance matrix, and from-to chart of annual flows for Case 1.

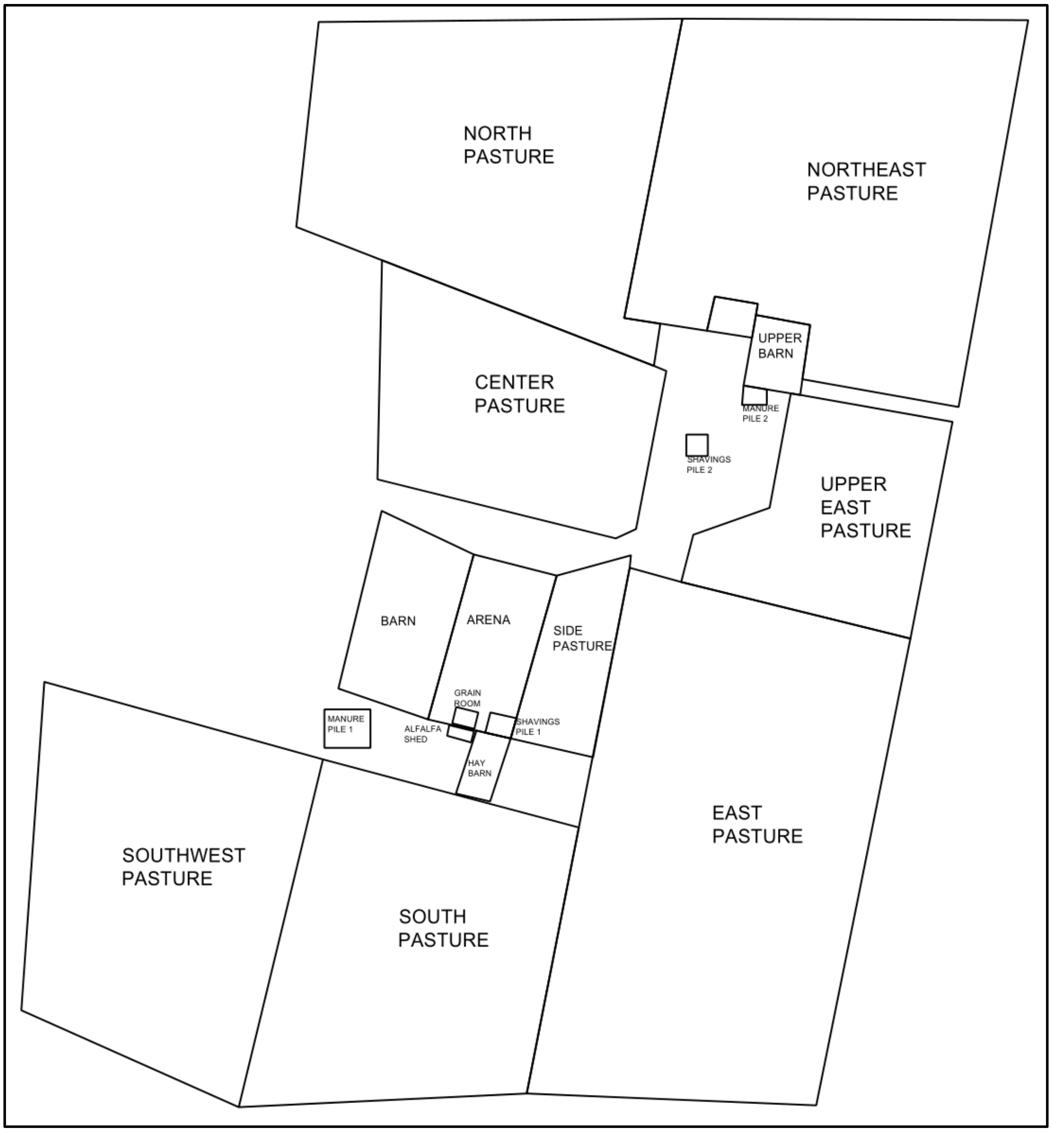


Figure 10: Case 1 Original Facility

Figure 11 shows the facility representation of Case 1 which was used to test the proposed optimization algorithm. Large pastures were divided into smaller pastures to be more compatible with other departments. The Barn and Arena departments were fixed (i.e. not included in any subsets) because of the difficulty and cost associated with moving them.

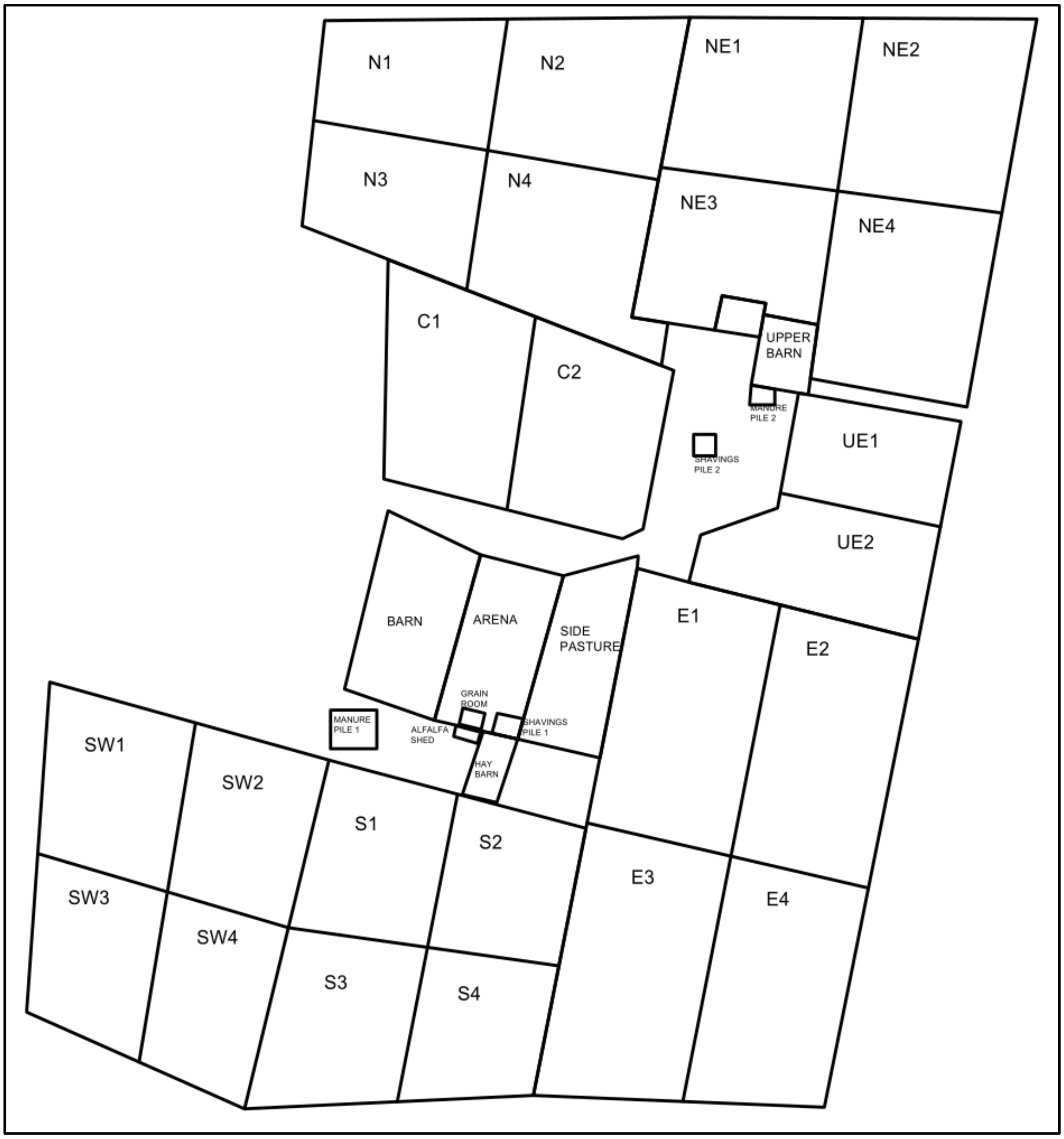


Figure 11: Case 1 Facility Representation

The subsets that were built for the layout improvement algorithm organized the departments into the following sets:

Table 1: Case 1 Subsets

Subset	Department
1	Grain Room Alfalfa Shed Manure Pile 1 Manure Pile 2 Shavings Pile 1 Shavings Pile 2
2	Hay Barn Upper Barn
3	Side Pasture S1 S2 S3 S4 SW1 SW2 SW3 SW4
4	N1 N2 N3 N4 NE1 NE2 NE3 NE4 E1 E2 E3 E4
5	UE1 UE2 C1 C2

The algorithm was able to improve the facility layout by 7% within four iterations and took 164 seconds to complete. The Alfalfa Shed, Shavings Pile 2, Grain

Room, and Manure Pile 1 departments were exchanged to improve the layout. These changes are illustrated in Figure 12, which depicts the facility layout results for Case 1.

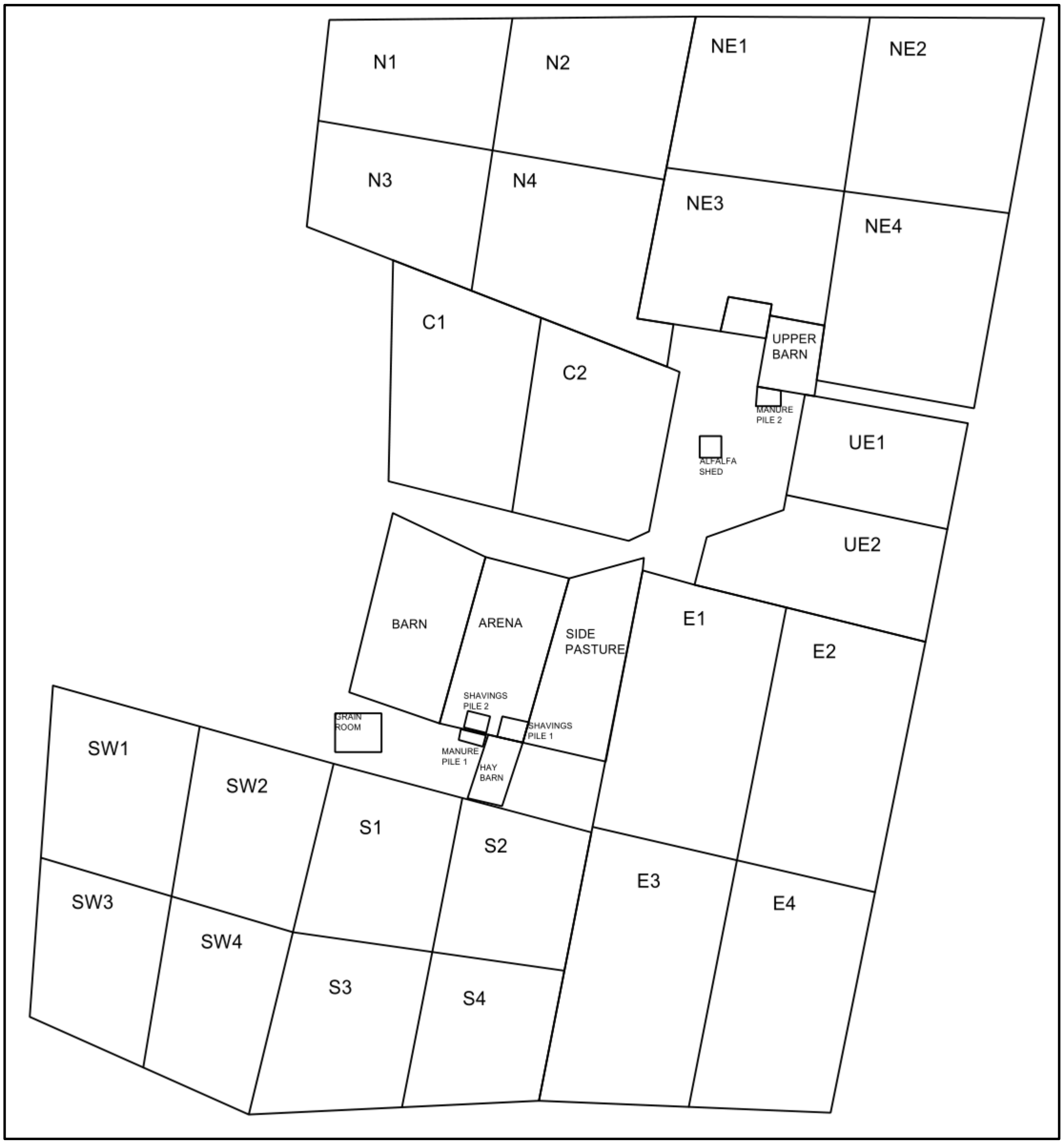


Figure 12: Case 1 Facility Results

The exchanges made by the algorithm are feasible because only departments with similar areas were exchanged, meaning that these departments would fit easily within the area occupied by the current department. In addition, the changes required to modify the original facility to the improved layout would not be drastic.

This layout could possibly be improved further with the insertion of several buildable spaces. Since it is more desirable to have the Alfalfa Shed centrally located with its higher flow levels than Shavings Pile 2, it may be beneficial to introduce buildable spaces on the south and east sides of pasture C2. These spaces should be of similar areas to those in *Subset 1* so they may be included in the subset and considered for exchange. With the addition of buildable spaces, it may be possible to locate the Alfalfa Shed centrally without relocating Shavings Pile 2 so far from the Upper Barn where its materials are used.

4.3 Results for Case 2

Case 2 is a large facility with a very relaxed limitation in the amount of space available when compared to Case 1. The facility spans approximately 48 acres with a small, centralized barn and storage area surrounded by pastures. Figure 13 gives a top-down view of the whole facility, while Figure 14 is a more detailed view of the centralized barn space.

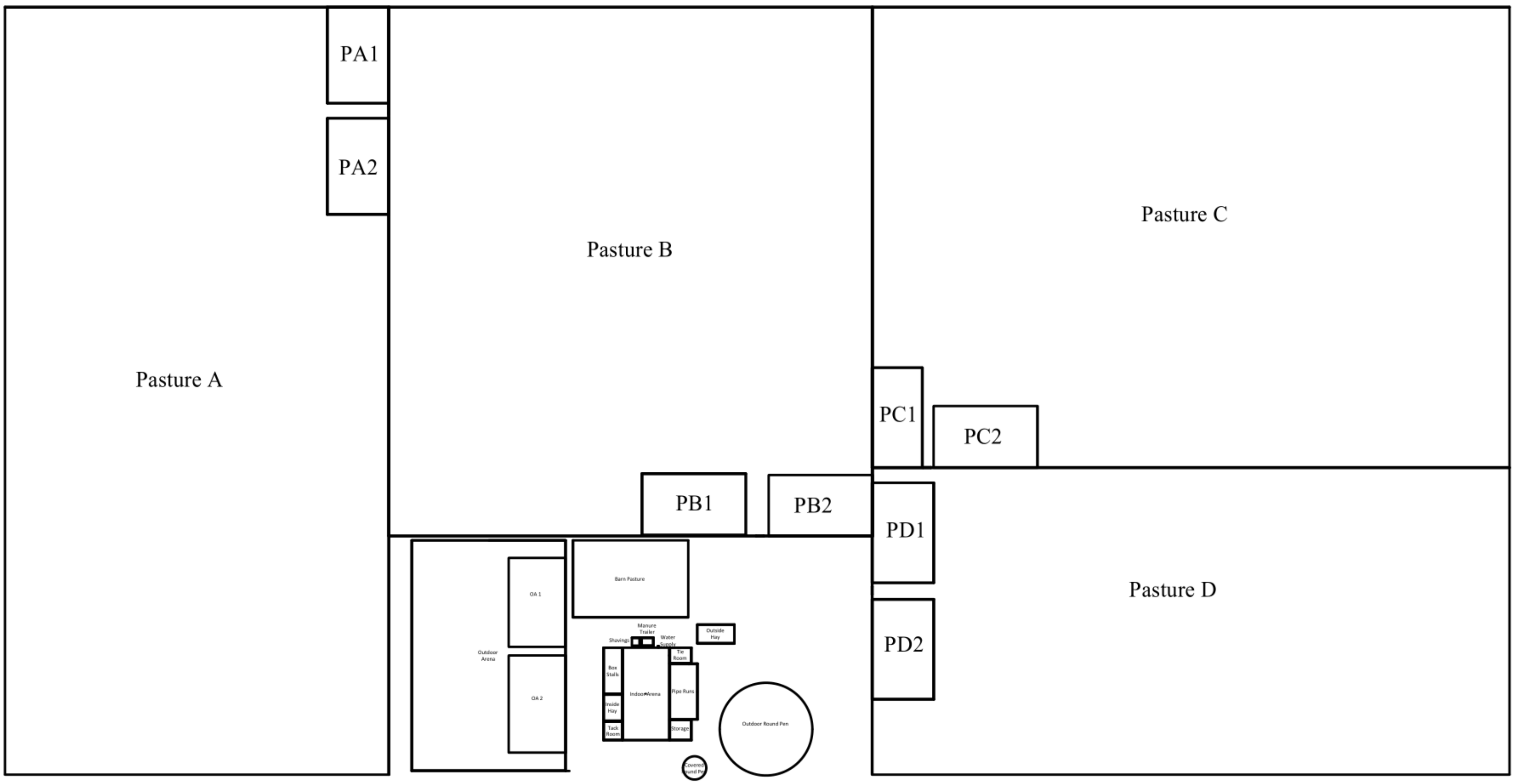


Figure 13: Case 2 Facility Representation Top-Down View

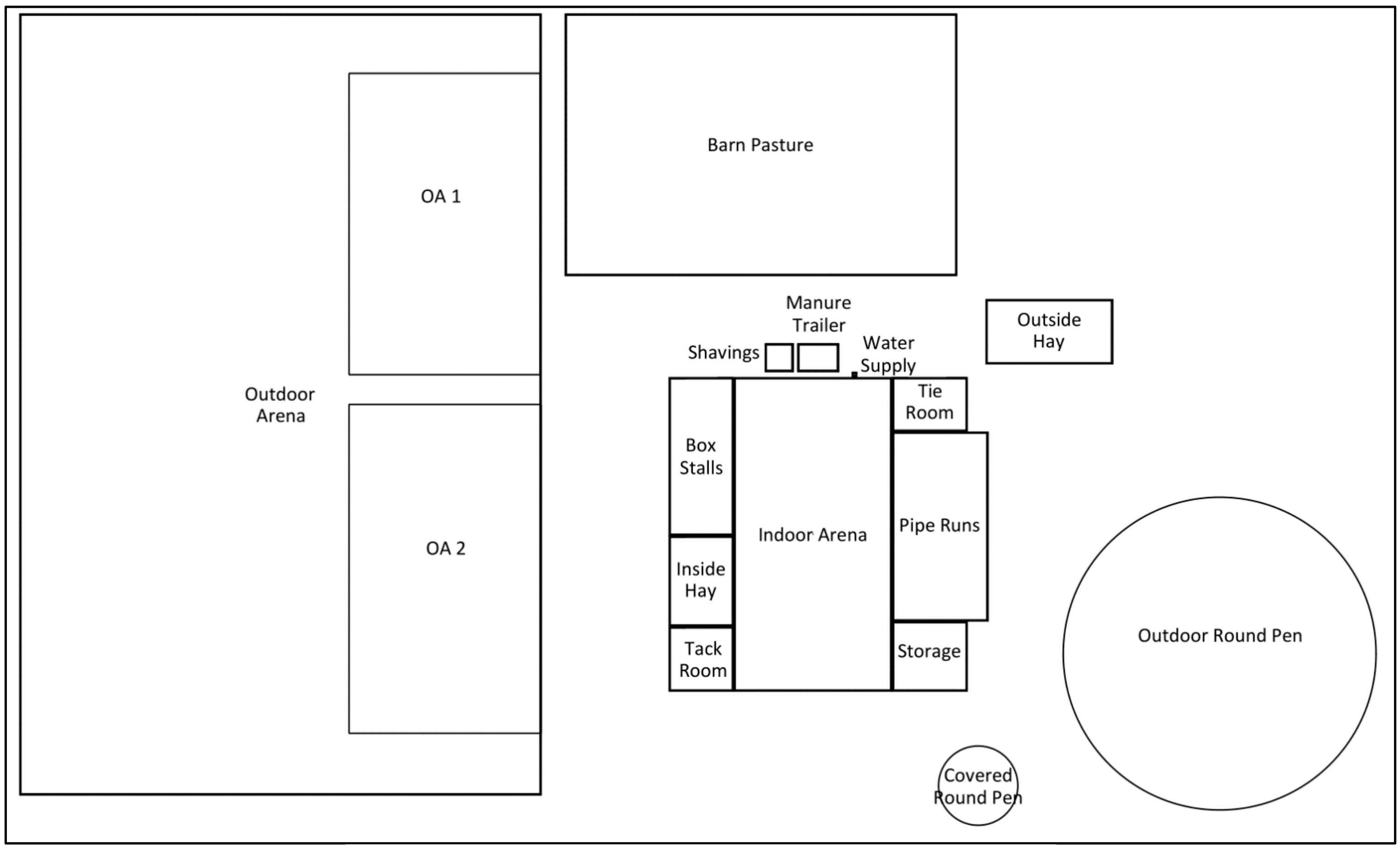


Figure 14: Case 2 Facility Representation Detail View

The Case 2 facility is used for the breeding, training, and sale of racehorses. It is a private facility and is the livelihood of the owners. The nature of this training facility makes all flows vital to its operation, including movement of horses between stalls, pastures, and training spaces such as the round pens and arenas. For this case, all activities were included in the flow data for the annual and seasonal from-to charts. See Appendix B for the department key, distance matrix, and from-to charts.

As shown in Figures 13 and 14, small portions of larger spaces, e.g. the pastures and Outdoor Arena, were identified as areas of importance and thus smaller departments were created to make more exchanges possible. These smaller departments are named using numbered abbreviations of the original department's name; the Outdoor Arena was split into departments OA 1 and OA 2. With the training and livestock handling flows included in this test case, three different scenarios were developed and tested to reflect the seasonal changes in activity flows which are dictated by weather. A summer, winter, and annual scenario were each tested to determine what would be the best configurations for summer, winter, and throughout the year (annual). The distance matrices and subsets for each of these cases are identical, but the flows change depending upon the time of year. The departments for all three scenarios were organized into the following subsets:

Table 2: Case 2 Subsets

Subset	Department
1	Tie Room Tack Room Inside Hay Storage
2	Barn Pasture OA 1 OA 2
3	Outside Hay Box Stalls Pipe Run
4	Shavings Manure Trailer
5	Covered Round Pen Outdoor Round Pen
6	PA1 PA2 PB1 PB2 PC1 PC2 PD1 PD2

The results for the summer, winter, and annual approaches can be found in sections 4.2.1, 4.2.2, and 4.2.3, respectively.

4.3.1 Summer

The summer scenario for Case 2 includes flows to and from the Pipe Runs, Outdoor Arena, and Outdoor Round Pen. It is assumed that all horses in training will be housed in the Pipe Runs, which are not covered, because the weather will not cause issues with training. It is also assumed that the Outdoor Arena and the Outdoor Round Pen are used exclusively for training purposes since the nicer weather allows for the use of these larger spaces.

The algorithm was able to improve the layout by 7% within four iterations and took 51 seconds to reach a final solution. Overall, five departments were exchanged: the Tack Room, OA 2, Storage, Covered Round Pen, Outdoor Round Pen, and the Barn Pasture. The effects of these changes on the final layout of the Case 2 facility can be seen in Figure 15.

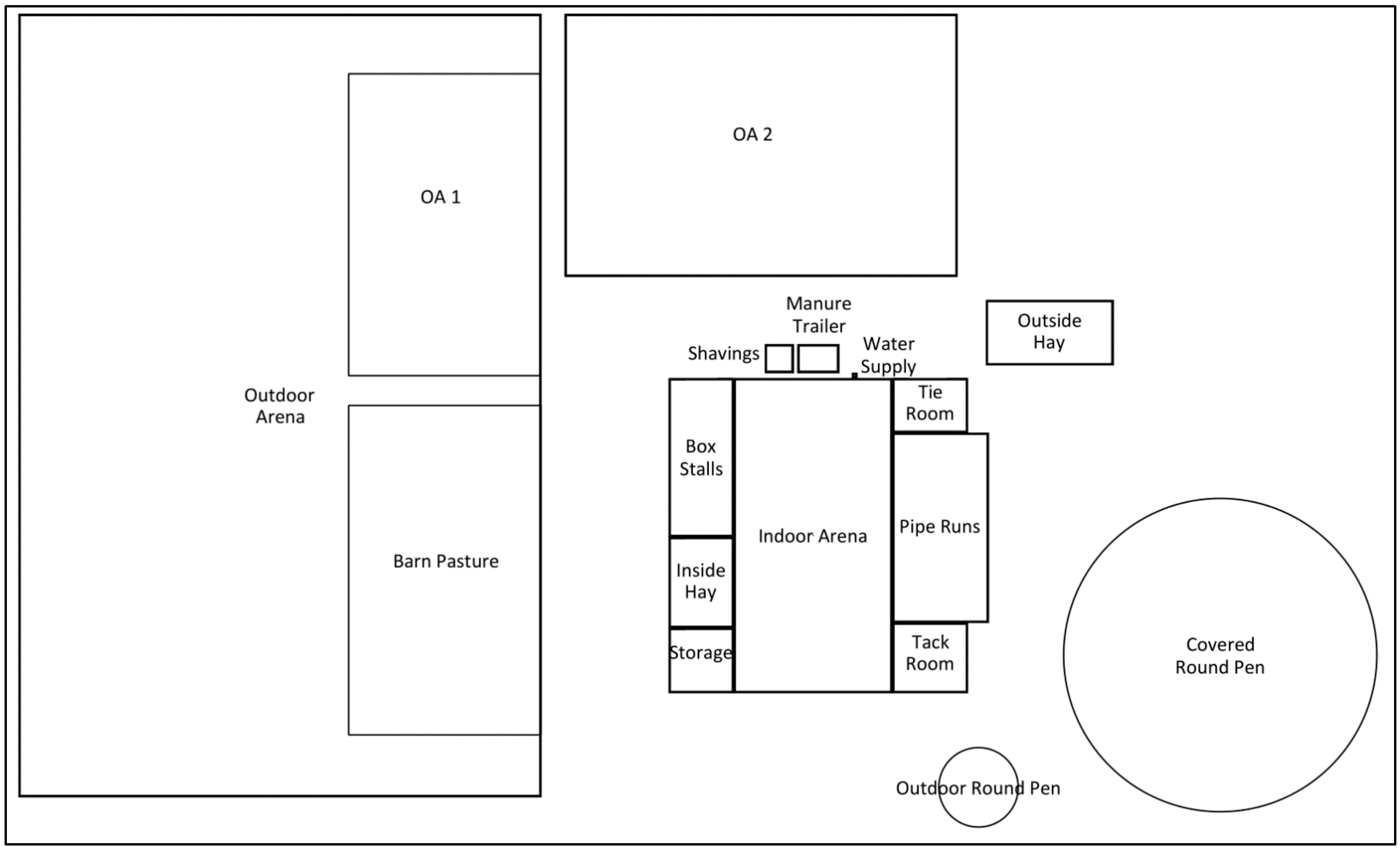


Figure 15: Case 2 Summer Results

The exchanges made by the algorithm are mostly feasible, but would require significant work to implement in some cases. Exchanging the Tack Room and Storage would be a fairly easy task, simply requiring remodeling the interior of these existing rooms which have the same footprint. However, exchanging the round pens and OA 2 with the Barn Pasture is much more intensive. Exchanging OA 2 with the Barn Pasture would require converting the Barn Pasture into an arena, which would require extensive ground work and new footing (e.g. sand, dirt, etc.) to be purchased and lain. Converting OA 2 to a Pasture, however, would be simpler since it would only require a fence to be installed and grass to be grown. If having forage (e.g. grass) available inside the new area was not a requirement, then only a fence would be required. In addition, this exchange would drastically reduce the size and usefulness of the Outdoor Arena as a whole, and thus is not a wise choice for exchange.

The third exchange of the two round pens would perhaps require the most work of all and it would not produce the exact results generated by the algorithm in reality. This is because the algorithm exchanges the centroids (centers) of two departments and therefore assumes the Outdoor Round Pen can take the place of the Covered Round Pen without issue. This is obviously untrue since the walls of the Outdoor Round Pen would run into the Tack Room and Indoor Arena if the centroids were exchanged perfectly. This is one of the instances where it would be advisable to modify the layout by exchanging the round pens in a realistic fashion, update the distance matrix with these changes, and run the algorithm again to evaluate whether or not this exchange would be beneficial in reality.

While some of the suggested changes are obviously more feasible than others, it is important to remember that these changes may only be beneficial for a portion of the year while the weather is amenable. In particular, the exchange of the round pens and the Barn Pasture with OA 2 cater specifically to this season since these exchanges move the most frequented training areas closer to the Pipe Runs, Tie Room, and Tack Room which are used extensively during training.

4.3.2 Winter

The winter scenario for Case 2 includes flows to and from the Box Stalls, Indoor Arena, and Covered Round Pen. It is assumed that all horses in training will be housed in the Box Stalls, which are completely enclosed, and that the Indoor Arena and Covered Round Pen are used exclusively for training purposes since both are covered and the weather generally makes the outdoor spaces unusable, due to snow and frozen ground which can be unsuitable for riding or training purposes.

The algorithm was able to improve this layout by 7% within three iterations and took 24 seconds to reach a final solution. Only two departments were exchanged for this algorithm: Inside Hay and the Tie Room. The effects of these changes on the final layout of the Case 2 facility can be seen in Figure 16.

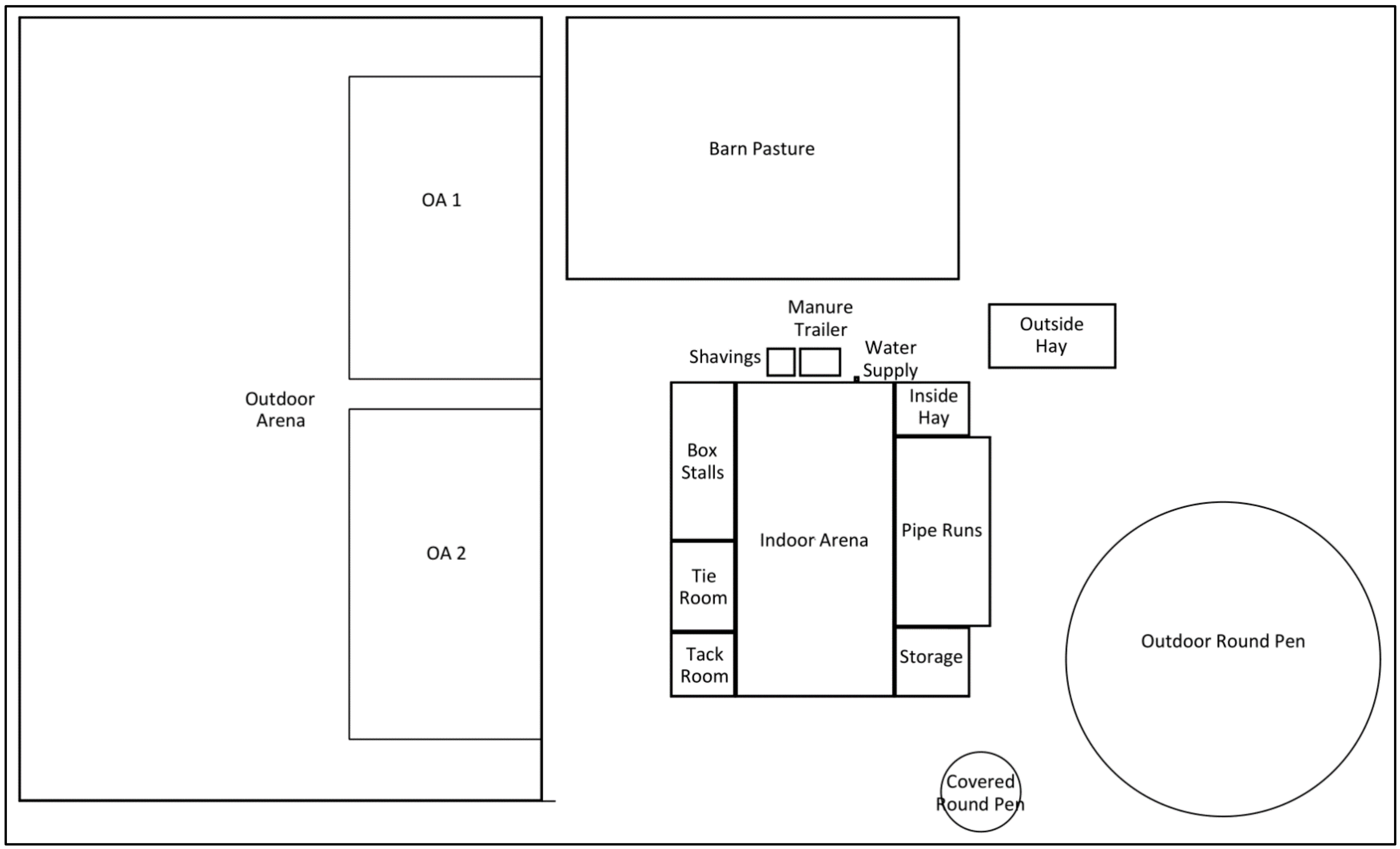


Figure 16: Case 2 Winter Results

Exchanging the Inside Hay and Tie Room departments makes the Tie Room adjacent to the Tack Room and the Box Stalls, both of which the Tie Room has high flows between in order to prepare horses for training. The Indoor Arena is adjacent to all three of these departments and the Covered Round Pen is the closest of the remaining training areas, so it was not exchanged with any other departments. This is a very efficient layout for winter training purposes; exchanging the Tie Room and Inside Hay is feasible and should be simple to implement.

4.3.3 Annual

The annual scenario for Case 2 includes flows to all training spaces and both the Box Stalls and the Pipe Runs. This scenario is meant to give an average of the yearly training flows. In the summer and winter scenarios it was assumed that four horses would be housed within the barn at any given time, and two horses each would be worked in the two training spaces allocated to each season. In the annual approach it is still assumed that four horses will be housed within the barn on average, but two of them are housed in the Box Stalls and two in the Pipe Runs. Each of the four horses are worked in one of the four training spaces. In this way, the flows are equalized throughout the year to give an annual usage average to determine what will be the most beneficial improvements year-round.

The algorithm was able to improve the layout by 6% within four iterations and took 35 seconds to reach a final solution. Three departments were exchanged to reach the final solution: Inside Hay, the Tack Room, and the Tie Room. The effects of these changes on the final layout of the Case 2 facility can be seen in Figure 17.

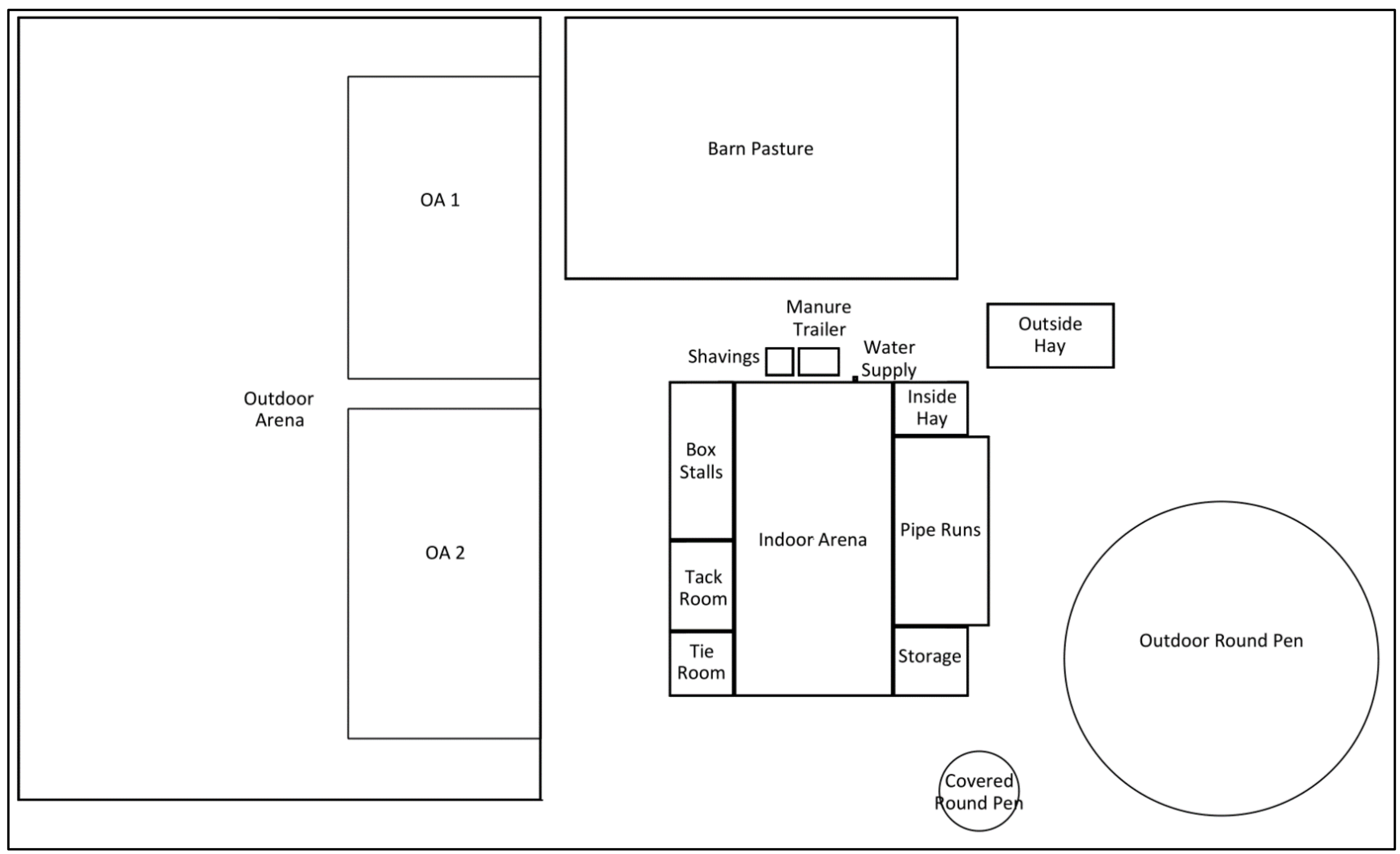


Figure 17: Case 2 Annual Results

The exchanges of the Tie Room, Tack Room, and Inside Hay improve the facility layout throughout the year. There are high flows between the Tie Room and Tack Room so having these two departments adjacent to one another limits the distance which is repeatedly travelled. With the Tie Room located in the southwest corner of the barn, it is centrally located between the training spaces which allows for the shortest distance since all horses are tacked up (saddled or prepared for training) and untacked in the Tie Room before and after training.

These exchanges are feasible because the departments are close in area and would improve the layout on an annual basis, which will be the most effective change year-round. These exchanges would also be fairly simple to implement since they do not require any major reworking of the ground or new buildings.

5 DISCUSSION

5.1 Test Cases

In each of the test cases, the optimization algorithm was able to find a solution with an improved layout despite the differences between the two facilities that were considered. Case 1 and Case 2 differ in that they each represent facilities in very different areas and cultures with substantial variations in the layouts, distances, and flows.

Case 1 in the Willamette Valley shows a facility with a limited amount of space filled with many departments which have been slowly added to the facility over the years. The space constraints and density of departments makes the exchange of departments within this facility more difficult and possibly more expensive to implement. Equine facilities in the Willamette Valley are generally close to urban areas to help decrease the transportation distance and time for boarders, meaning that many will still be subject to specific building ordinances. If new buildings are required, it is likely that they will require permits and other legal approvals before they can be built which increases cost. In contrast, the Case 2 facility is based on the Umatilla Indian Reservation which is a large facility with virtually unlimited space that is subject to an entirely different legislative process. With respect to legal matters, it would be much easier to exchange departments or add new buildings for facilities on reservations than for those close to urban areas.

With respect to flows between departments and distances, Case 1 and Case 2 are on opposite ends of the spectrum. Case 2 has fewer departments, lower flow rates, and significantly longer distances to travel. Case 1 has many departments with high flows but relatively short distances between the departments.

These differences are again representative of the different cultures and communities they belong to. The high number of horses on such a small property in Case 1 means that the pastures cannot be relied upon to provide adequate forage for the horses, causing higher flows to hay barns as all feed must be stored and provided by facility personnel. Case 2 has twice as many horses but is situated on a property nearly five times the size of Case 1, meaning lower flows to feed storage areas throughout the year as the large pastures can provide adequate forage for part of the year.

Despite the many differences between these two facilities, both cases can still be solved using the same analytical approach. All of the differences between these two facilities are captured by the flow and distance data input into the improvement algorithm, which is the only difference in the actual application of the method.

5.2 Relevance

While applying industrial engineering facility planning methods to the equine facility layout problem may be unconventional, the horse industry is one which can benefit greatly—even from small changes such as these. Above all, working with horses is a time-consuming activity and when horses are your livelihood, as with Case 2, it becomes even more time intensive. Being able to shorten the overall distance travelled in a facility with a more efficient layout may not work out to provide impressive cost savings, but the time gained by the facility personnel will be extremely valuable. The time gained could then be invested in training more horses per day for a training-based facility or simply allow owners to spend more time with their companions in a boarding facility.

More importantly, the determination of what modifications to make to an existing facility is not a trivial task due to the number of different possibilities that can be evaluated. The developed algorithm provides a method to systematically evaluate the potential improvements in an efficient and quantifiable way. This is significant because it bridges the gap between two seemingly unrelated fields—industrial engineering principles and the equine industry—to make efficient facility planning an accessible option for equine facility owners.

5.3 Methodology Differentiation

What makes the proposed methodology presented in this research unique are the user-defined subsets to capture feasible exchanges, and the use of a “greedy” algorithm rather than the traditional “steepest descent” method to improve a layout. Greedy algorithms immediately implement the first improvement in the objective function rather than waiting for an iteration to be completed to implement the largest improvement, as with steepest descent optimization. The subsets eliminate the adjacency and same area limitations of other facility layout methods, making it a more versatile method which can be applied to the equine facility layout problem. The downfall of these subsets is the subjectivity behind the selection of the departments to be included in a subset and the number of subsets needed to improve the performance of the algorithm.

5.4 Application

The method described above is meant to be simple to implement and easily attainable by any persons looking to improve their facilities. The resulting layout plans generated should be simple and economic to implement, so that they can be put into practice relatively quickly. A primary focus of this study was to ensure that the developed method would also be applicable and accessible to facilities within the Native American community. In general, boarding facilities do not exist on reservations in the Pacific Northwest because space is available for people to house their horses on their own property. This means that large equine facilities on reservations are most often the owner's livelihood and are used as breeding and training facilities, the basis for the facility modeled in Case 2. From the results for Case 2, it can be seen that improvements can still be possible at facilities that have an abundance of space.

Access to this method for the Native American community may be difficult because of the technology it requires to run the algorithm. However, with the recent installation of a technology center on the Umatilla Indian Reservation, it would be much easier to access the technology necessary to use the algorithm than it was in the past. In order for this method to be the most effective, a guide should be created to explain the methodology with very little engineering jargon and in terms with which those in the equine industry could readily relate. This guide would include test cases which would be relevant to different types of users considering a wide variety of equine facilities. Preferences of the user should be included in the design of such a decision support tool, but more research—likely in the form of surveys—is needed to gauge acceptability of the proposed method as well as preferences for usage and the interpretation of the results.

6 CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

The proposed methodology developed in this study is a tool that can be utilized by equine facilities to help improve their layouts in order to save time and eventually reduce costs. The method was developed in such a way as to cater to all different types of facilities within multiple cultures to allow for the greatest possible benefit. The test cases were based on facilities in both the Willamette Valley and on the Umatilla Indian Reservation in eastern Oregon to test the versatility of the developed method, which proved to be applicable for both cases. The algorithm was able to reduce the overall annual distance travelled in Case 1 and Case 2 by 7% and 6%, respectively. The use of the user-defined subsets eliminates traditional issues with standard facility layout methods that are not able to exchange non-adjacent, unequal area departments.

6.2 Future Work

Future work in this area should include a study where extensive computational experiments are completed to evaluate the effectiveness and performance of the algorithm itself. The method developed in this study should be modified to use a steepest descent approach and then compared to the greedy algorithm developed in this study to determine if a greedy or steepest descent approach is more efficient. The developed method could also be applied to livestock facilities in other agricultural industries to help reduce costs and save other valuable resources. Finally, as discussed in Section 5.4, more work is needed to make the proposed methodology more accessible to all potential users by exploring their different requirements and preferences and addressing them when developing a decision support tool that is acceptable and useful.

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APPENDICES

Appendix A: Case 1 Data

Table A1: Case 1 Department Key

Department Code	Department Name	Subset Number
--	Barn	--
--	Arena	--
--	Grain room	1
--	Alfalfa Shed	1
--	Hay barn	2
--	Manure Pile 1	1
--	Manure Pile 2	1
--	Shavings Pile 1	1
--	Shavings Pile 2	1
--	Upper Barn	2
--	Side pasture	3
N1	North Pasture 1	4
N2	North Pasture 2	4
N3	North Pasture 3	4
N4	North Pasture 4	4
NE1	Northeast Pasture 1	4
NE2	Northeast Pasture 2	4
NE3	Northeast Pasture 3	4
NE4	Northeast Pasture 4	4
UE1	Upper East Pasture 1	5
UE2	Upper East Pasture 2	5
E1	East Pasture 1	4
E2	East Pasture 2	4
E3	East Pasture 3	4
E4	East Pasture 4	4
S1	South Pasture 1	3
S2	South Pasture 2	3
S3	South Pasture 3	3
S4	South Pasture 4	3
SW1	Southwest Pasture 1	3
SW2	Southwest Pasture 2	3
SW3	Southwest Pasture 3	3
SW4	Southwest Pasture 4	3
C1	Center Pasture 1	5
C2	Center Pasture 2	5

Table A2: Case 1 Distance Matrix

	Barn	Arena	Grain room	Alfalfa Shed	Hay barn	Manure Pile 1	Manure Pile 2	Shavings Pile 1	Shavings Pile 2	Upper Barn	Side pasture
Barn	--	65	150	165	185	215	377	142	347	434	293
Arena	65	--	150	165	185	215	392	77	347	433	292
Grain room	150	150	--	55	75	105	478	227	433	519	378
Alfalfa Shed	165	165	55	--	55	100	493	242	448	534	393
Hay barn	185	185	75	55	--	120	513	262	468	554	413
Manure Pile 1	215	215	105	100	120	--	543	292	498	584	443
Manure Pile 2	377	392	478	493	513	543	--	469	97	72	270
Shavings Pile 1	142	77	227	242	262	292	469	--	424	510	369
Shavings Pile 2	347	347	433	448	468	498	97	424	--	121	213
Upper Barn	434	433	519	534	554	584	72	510	121	--	225
Side pasture	293	292	378	393	413	443	270	369	213	225	--
N1	656	655	741	756	776	806	405	732	360	504	629
N2	556	555	641	656	676	706	305	632	260	404	529
N3	575	574	660	675	695	725	324	651	279	423	548
N4	450	449	535	550	570	600	199	526	154	298	423
NE1	579	578	664	679	699	729	228	655	283	200	499
NE2	699	698	784	799	819	944	443	775	386	265	564
NE3	479	478	564	579	599	629	128	555	183	100	399
NE4	576	575	661	676	696	821	320	652	263	142	441
UE1	439	438	524	539	559	589	116	515	170	125	304
UE2	384	383	469	484	504	534	250	460	188	274	249
E1	414	413	499	514	534	564	280	490	218	304	279
E2	522	521	607	622	642	672	388	598	326	412	387
E3	602	601	687	702	722	752	468	678	406	492	467
E4	702	701	787	802	822	852	568	778	506	592	567
S1	243	242	132	137	127	177	570	319	525	611	480
S2	296	295	185	190	180	230	623	372	578	664	533
S3	357	356	246	251	241	291	684	433	639	725	594
S4	447	446	336	341	331	381	774	523	729	815	684
SW1	409	408	298	293	313	213	736	485	691	777	646
SW2	319	318	208	203	223	123	646	395	601	687	556
SW3	526	525	415	420	430	330	853	602	808	894	763
SW4	443	442	332	327	347	247	770	519	725	811	680
C1	228	227	313	328	348	378	250	304	305	391	250
C2	273	272	358	373	393	423	350	349	205	286	155

Table A2: Case 1 Distance Matrix (cont.)

	N1	N2	N3	N4	NE1	NE2	NE3	NE4	UE1	UE2	E1	E2	E3	E4	S1	S2	S3	S4	SW1	SW2	SW3	SW4	C1	C2
Barn	656	556	575	450	579	699	479	576	439	384	414	522	602	702	243	296	357	447	409	319	526	443	228	273
Arena	655	555	574	449	578	698	478	575	438	383	413	521	601	701	242	295	356	446	408	318	525	442	227	272
Grain room	741	641	660	535	664	784	564	661	524	469	499	607	687	787	132	185	246	336	298	208	415	332	313	358
Alfalfa Shed	756	656	675	550	679	799	579	676	539	484	514	622	702	802	137	190	251	341	293	203	420	327	328	373
Hay barn	776	676	695	570	699	819	599	696	559	504	534	642	722	822	127	180	241	331	313	223	430	347	348	393
Manure Pile 1	806	706	725	600	729	944	629	821	589	534	564	672	752	852	177	230	291	381	213	123	330	247	378	423
Manure Pile 2	405	305	324	199	228	443	128	320	116	250	280	388	468	568	570	623	684	774	736	646	853	770	250	350
Shavings Pile 1	732	632	651	526	655	775	555	652	515	460	490	598	678	778	319	372	433	523	485	395	602	519	304	349
Shavings Pile 2	360	260	279	154	283	386	183	263	170	188	218	326	406	506	525	578	639	729	691	601	808	725	305	205
Upper Barn	504	404	423	298	200	265	100	142	125	274	304	412	492	592	611	664	725	815	777	687	894	811	391	286
Side pasture	629	529	548	423	499	564	399	441	304	249	279	387	467	567	480	533	594	684	646	556	763	680	250	155
N1	--	125	81	206	549	699	449	576	531	660	690	798	878	978	997	1050	1111	1201	1163	1073	1280	1197	721	616
N2	125	--	231	125	444	574	344	451	431	560	590	698	778	878	898	951	1012	1102	1064	974	1181	1098	621	516
N3	81	231	--	125	463	688	363	565	450	579	609	717	797	897	860	913	974	1064	1016	926	1133	1050	640	535
N4	206	125	125	--	348	563	248	440	325	454	484	592	672	772	792	845	906	996	958	868	1075	992	572	467
NE1	549	444	463	348	--	166	100	219	401	540	570	678	758	858	877	930	991	1081	1043	953	1160	1077	657	552
NE2	699	574	688	563	166	--	290	123	432	561	591	699	779	879	978	1031	1092	1182	1144	1054	1261	1178	678	653
NE3	449	344	363	248	100	290	--	166	301	440	470	578	658	758	777	830	891	981	943	853	1060	977	557	452
NE4	576	451	565	440	219	123	166	--	314	438	468	576	656	756	775	828	889	979	941	851	1058	975	555	450
UE1	531	431	450	325	401	432	301	314	--	279	309	417	497	597	696	749	810	900	862	772	979	985	396	371
UE2	660	560	579	454	540	561	440	438	279	--	248	356	436	536	555	608	669	759	721	631	838	755	335	230
E1	690	590	609	484	570	591	470	468	309	248	--	108	188	288	571	624	685	775	737	647	854	771	351	246
E2	798	698	717	592	678	699	578	576	417	356	108	--	296	396	693	746	807	897	859	769	976	893	473	368
E3	878	778	797	672	758	779	658	656	497	436	188	296	--	100	773	826	887	977	939	849	1056	973	553	448
E4	978	878	897	772	858	879	758	756	597	536	288	396	100	--	873	926	987	1077	1039	949	1156	1073	653	548
S1	997	898	860	792	877	978	777	775	696	555	571	693	773	873	--	68	76	166	370	280	487	404	405	450
S2	1050	951	913	845	930	1031	830	828	749	608	624	746	826	926	68	--	61	151	423	333	540	457	458	503
S3	1111	1012	974	906	991	1092	891	889	810	669	685	807	887	987	76	61	--	90	484	394	601	518	519	564
S4	1201	1102	1064	996	1081	1182	981	979	900	759	775	897	977	1077	166	151	90	--	574	484	691	608	609	654
SW1	1163	1064	1016	958	1043	1144	943	941	862	721	737	859	939	1039	370	423	484	574	--	90	124	214	571	616
SW2	1073	974	926	868	953	1054	853	851	772	631	647	769	849	949	280	333	394	484	90	--	207	124	481	526
SW3	1280	1181	1133	1075	1160	1261	1060	1058	979	838	854	976	1056	1156	487	540	601	691	124	207	--	83	688	733
SW4	1197	1098	1050	992	1077	1178	977	975	985	755	771	893	973	1073	404	457	518	608	214	124	83	--	605	650
C1	721	621	640	572	657	678	557	555	396	335	351	473	553	653	405	458	519	609	571	481	688	605	--	230
C2	616	516	535	467	552	653	452	450	371	230	246	368	448	548	450	503	564	654	616	526	733	650	230	--

Table A3: Case 1 From-to Chart

	Barn	Arena	Grain room	Alfalfa Shed	Hay barn	Manure Pile 1	Manure Pile 2	Shavings Pile 1	Shavings Pile 2	Upper Barn	Side pasture
Barn	--		2	2	2	5		5			
Arena		--									
Grain room	2		--							1	1
Alfalfa Shed	2			--						2	2
Hay barn	2				--						2
Manure Pile 1	5					--					
Manure Pile 2							--			3	
Shavings Pile 1	5							--			
Shavings Pile 2									--	2	
Upper Barn			1	2			3		2	--	
Side pasture			1	2	2						--
N1			1	2						2	
N2			1	2						2	
N3			1	2						2	
N4			1	2						2	
NE1			1	2						2	
NE2			1	2						2	
NE3			1	2						2	
NE4			1	2						2	
UE1			1	2						2	
UE2			1	2						2	
E1			1	2	2						
E2			1	2	2						
E3			1	2	2						
E4			1	2	2						
S1			1	2	2						
S2			1	2	2						
S3			1	2	2						
S4			1	2	2						
SW1			1	2	2						
SW2			1	2	2						
SW3			1	2	2						
SW4			1	2	2						
C1			1	2	2						
C2			1	2	2						

Table A3: Case 1 From-to Chart (cont.)

	N1	N2	N3	N4	NE1	NE2	NE3	NE4	UE1	UE2	E1	E2	E3	E4	S1	S2	S3	S4	SW1	SW2	SW3	SW4	C1	C2
Barn																								
Arena																								
Grain room	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alfalfa Shed	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Hay barn											2	2	2	2	2	2	2	2	2	2	2	2	2	2
Manure Pile 1																								
Manure Pile 2																								
Shavings Pile 1																								
Shavings Pile 2																								
Upper Barn	2	2	2	2	2	2	2	2	2	2														
Side pasture																								
N1	--																							
N2		--																						
N3			--																					
N4				--																				
NE1					--																			
NE2						--																		
NE3							--																	
NE4								--																
UE1									--															
UE2										--														
E1											--													
E2												--												
E3													--											
E4														--										
S1															--									
S2																--								
S3																	--							
S4																		--						
SW1																			--					
SW2																				--				
SW3																					--			
SW4																						--		
C1																							--	
C2																								--

Appendix B: Case 2 Data

Table B1: Case 2 Department Key

Department Code	Department Name	Subset Number
--	Box Stalls	3
--	Tack Room	1
--	Inside Hay	1
--	Outside Hay	3
--	Pipe Runs	3
--	Tie Room	1
--	Manure Trailer	4
--	Shavings	4
--	Indoor Arena	--
OA 1	Outdoor Arena 1	2
OA 2	Outdoor Arena 2	2
--	Storage	1
--	Covered Round Pen	5
--	Outdoor Round Pen	5
--	Barn Pasture	2
--	Water Spigot	--
PA1	Pasture A 1	6
PA2	Pasture A 2	6
PB1	Pasture B 1	6
PB2	Pasture B 2	6
PC1	Pasture C 1	6
PC2	Pasture C 2	6
PD1	Pasture D 1	6
PD2	Pasture D 2	6

Table B2: Case 2 Distance Matrix

	Box Stalls	Tack Room	Inside Hay	Outside Hay	Pipe Runs	Tie Room	Manure Trailer	Shavings	Indoor Arena	OA 1	OA 2	Storage
Box Stalls	--	103	73	188	227	176	109	94	79	225	256	213
Tack Room	103	--	55	266	190	233	187	172	127	303	188	135
Inside Hay	73	55	--	236	220	206	157	142	67	273	218	165
Outside Hay	188	266	236	--	148	97	99	114	169	293	349	193
Pipe Runs	227	190	220	148	--	80	138	153	58	319	469	70
Tie Room	176	233	206	97	80	--	87	102	101	281	337	126
Manure Trailer	109	187	157	99	138	87	--	35	159	214	270	170
Shavings	94	172	142	114	153	102	35	--	148	199	255	185
Indoor Arena	79	127	67	169	58	101	159	148	--	280	336	98
OA 1	225	303	273	293	319	281	214	199	280	--	150	378
OA 2	256	188	218	349	469	337	270	255	336	150	--	265
Storage	213	135	165	193	70	126	170	185	98	378	265	--
Covered Round Pen	194	101	151	343	135	104	344	263	171	395	245	178
Outdoor Round Pen	322	174	275	228	228	245	274	392	243	524	374	272
Barn Pasture	149	227	197	183	222	171	104	89	203	254	310	266
Water Spigot	129	207	177	91	103	53	40	55	126	234	290	147
PA1	1523	1601	1571	1370	1467	1416	1439	1454	1506	1640	1696	1510
PA2	1524	1602	1572	1370	1466	1415	1440	1455	1506	1640	1696	1509
PB1	500	578	548	347	443	392	416	431	483	617	673	486
PB2	492	570	540	338	435	384	408	423	474	608	664	478
PC1	818	896	866	630	727	676	700	715	766	900	956	770
PC2	830	908	878	643	739	688	712	727	779	913	969	782
PD1	598	676	646	410	507	456	480	495	546	680	736	550
PD2	600	678	648	412	508	457	481	496	548	682	738	551

Table B2: Case 2 Distance Matrix (cont.)

	Covered Round Pen	Outdoor Round Pen	Barn Pasture	Water Spigot	PA1	PA2	PB1	PB2	PC1	PC2	PD1	PD2
Box Stalls	194	322	149	129	1523	1524	500	492	818	830	598	600
Tack Room	101	174	227	207	1601	1602	578	570	896	908	676	678
Inside Hay	151	275	197	177	1571	1572	548	540	866	878	646	648
Outside Hay	343	228	183	91	1370	1370	347	338	630	643	410	412
Pipe Runs	135	228	222	103	1467	1466	443	435	727	739	507	508
Tie Room	104	245	171	53	1416	1415	392	384	676	688	456	457
Manure Trailer	344	274	104	40	1439	1440	416	408	700	712	480	481
Shavings	263	392	89	55	1454	1455	431	423	715	727	495	496
Indoor Arena	171	243	203	126	1506	1506	483	474	766	779	546	548
OA 1	395	524	254	234	1640	1640	617	608	900	913	680	682
OA 2	245	374	310	290	1696	1696	673	664	956	969	736	738
Storage	178	272	266	147	1510	1509	486	478	770	782	550	551
Covered Round Pen	--	210	378	368	1752	1753	729	721	1047	1060	827	829
Outdoor Round Pen	210	--	506	495	1880	1881	857	848	1175	1187	955	956
Barn Pasture	378	506	--	124	1501	1502	478	470	761	774	542	543
Water Spigot	368	495	124	--	1426	1427	403	405	686	699	467	469
PA1	1752	1880	1501	1426	--	145	1195	1189	1713	1725	1493	1495
PA2	1753	1881	1502	1427	145	--	1196	1190	1713	1726	1494	1495
PB1	729	857	478	403	1195	1196	--	167	690	703	470	472
PB2	721	848	470	405	1189	1190	166	--	681	694	462	463
PC1	1047	1175	761	686	1713	1713	690	681	--	140	219	372
PC2	1060	1187	774	699	1725	1726	703	694	140	--	232	384
PD1	827	955	542	467	1493	1494	470	462	219	232	--	152
PD2	829	956	543	469	1495	1495	472	463	372	384	152	--

Table B3: Case 2 Summer From-to Chart

	Box Stalls	Tack Room	Inside Hay	Outside Hay	Pipe Runs	Tie Room	Manure Trailer	Shavings	Indoor Arena	OA 1	OA 2	Storage
Box Stalls	--											
Tack Room		--				4						
Inside Hay			--		2							
Outside Hay				--								
Pipe Runs		4	2		--	4	1					
Tie Room		4			4	--				1	1	
Manure Trailer							--					
Shavings					1			--				
Indoor Arena									--			
OA 1						1				--		
OA 2						1					--	
Storage												--
Covered Round Pen												
Outdoor Round Pen						2						
Barn Pasture												
Water Spigot												
PA1				1								
PA2				1								
PB1				1								
PB2				1								
PC1				1								
PC2				1								
PD1				1								
PD2				1								

Table B3: Case 2 Summer From-to Chart (cont.)

	Covered Round Pen	Outdoor Round Pen	Barn Pasture	Water Spigot	PA1	PA2	PB1	PB2	PC1	PC2	PD1	PD2
Box Stalls												
Tack Room												
Inside Hay			2									
Outside Hay					1	1	1	1	1	1	1	1
Pipe Runs												
Tie Room		2										
Manure Trailer												
Shavings												
Indoor Arena												
OA 1												
OA 2												
Storage												
Covered Round Pen	--											
Outdoor Round Pen		--										
Barn Pasture			--									
Water Spigot				--	1	1	1	1	1	1	1	1
PA1				1	--							
PA2				1		--						
PB1				1			--					
PB2				1				--				
PC1				1					--			
PC2				1						--		
PD1				1							--	
PD2				1								--

Table B4: Case 2 Winter From-to Chart

	Box Stalls	Tack Room	Inside Hay	Outside Hay	Pipe Runs	Tie Room	Manure Trailer	Shavings	Indoor Arena	OA 1	OA 2	Storage
Box Stalls	--		2			4	1					
Tack Room		--				4						
Inside Hay	2		--									
Outside Hay				--								
Pipe Runs					--							
Tie Room	4	4				--			2			
Manure Trailer							--					
Shavings	1							--				
Indoor Arena						2			--			
OA 1										--		
OA 2											--	
Storage												--
Covered Round Pen						2						
Outdoor Round Pen												
Barn Pasture												
Water Spigot												
PA1				1								
PA2				1								
PB1				1								
PB2				1								
PC1				1								
PC2				1								
PD1				1								
PD2				1								

Table B4: Case 2 Winter From-to Chart (cont.)

	Covered Round Pen	Outdoor Round Pen	Barn Pasture	Water Spigot	PA1	PA2	PB1	PB2	PC1	PC2	PD1	PD2
Box Stalls												
Tack Room												
Inside Hay			2									
Outside Hay					1	1	1	1	1	1	1	1
Pipe Runs												
Tie Room	2											
Manure Trailer												
Shavings												
Indoor Arena												
OA 1												
OA 2												
Storage												
Covered Round Pen	--											
Outdoor Round Pen		--										
Barn Pasture			--									
Water Spigot				--	1	1	1	1	1	1	1	1
PA1				1	--							
PA2				1		--						
PB1				1			--					
PB2				1				--				
PC1				1					--			
PC2				1						--		
PD1				1							--	
PD2				1								--

Table B5: Case 2 Annual From-to Chart

	Box Stalls	Tack Room	Inside Hay	Outside Hay	Pipe Runs	Tie Room	Manure Trailer	Shavings	Indoor Arena	OA 1	OA 2	Storage
Box Stalls	--	2	2			2	1	1				
Tack Room		--				4						
Inside Hay	2		--		2							
Outside Hay				--								
Pipe Runs		2	2		--	2	1	1				
Tie Room	2	4			2	--			1	1	1	
Manure Trailer	1				1		--					
Shavings	1				1			--				
Indoor Arena						1			--			
OA 1						1				--		
OA 2						1					--	
Storage												--
Covered Round Pen						1						
Outdoor Round Pen						1						
Barn Pasture												
Water Spigot												
PA1				1								
PA2				1								
PB1				1								
PB2				1								
PC1				1								
PC2				1								
PD1				1								
PD2				1								

Table B5: Case 2 Annual From-to Chart (cont.)

	Covered Round Pen	Outdoor Round Pen	Barn Pasture	Water Spigot	PA1	PA2	PB1	PB2	PC1	PC2	PD1	PD2
Box Stalls												
Tack Room												
Inside Hay			2									
Outside Hay					1	1	1	1	1	1	1	1
Pipe Runs												
Tie Room	1	1										
Manure Trailer												
Shavings												
Indoor Arena												
OA 1												
OA 2												
Storage												
Covered Round Pen	--											
Outdoor Round Pen		--										
Barn Pasture			--									
Water Spigot				--	1	1	1	1	1	1	1	1
PA1				1	--							
PA2				1		--						
PB1				1			--					
PB2				1				--				
PC1				1					--			
PC2				1						--		
PD1				1							--	
PD2				1								--