A DECISION MAKING MODEL FOR HORSE TRANSPORTATION

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งานวิจัยนี้มีจุดประสงค์เพื่อพัฒนาแบบจำลองทางคณิตศาสตร์เพื่อเลือกรูปแบบการขนส่งม้าขี่ม้าที่เหมาะสมที่สุด ซึ่งสมดุลระหว่างค่าขนส่งและสวัสดิภาพของม้า การศึกษาแบ่งออกเป็น 2 ขั้นตอน ดังนี้ 1) เปรียบเทียบระดับความเครียดของม้าที่ขนส่งโดยใช้คอร์ติซอลกับอัตราการเต้นของหัวใจ 2) พัฒนาแบบจำลองทางคณิตศาสตร์ที่ปรับสมดุลสุขภาพของม้าและค่าขนส่ง การวิจัยครั้งนี้ใช้ม้า 6 ตัว โดยที่ม้าจะถูกขนส่งโดยยานพาหนะประเภทต่างๆ เช่น รถบรรทุกม้าขนาดใหญ่ที่มีเครื่องปรับอากาศ รถบรรทุกม้าขนาดใหญ่ที่ไม่มีเครื่องปรับอากาศ โดยการขนส่งแบบไม่มีที่ว่างและมีที่ว่าง และรถลากม้าขนาดเล็กที่ไม่มีเครื่องปรับอากาศ แบบมีไม่มีที่ว่าง และมีที่ว่าง การขนส่งใช้เวลา 5 ชั่วโมง ในระยะทาง 250 กิโลเมตร ม้าจะถูกขนส่งอาทิตย์ละ 2 ครั้งเป็นเวลา 3 สัปดาห์ ค่าระดับคอร์ติซอล (ค่าฮอร์โมนบ่งชี้ความเครียด) และค่าอัตราการเต้นของหัวใจถูกเก็บ ผลการวิจัยพบว่ารูปแบบการขนส่งที่แตกต่างกันส่งผลให้เกิดความเครียดในม้าต่างกัน แบบจำลองทางคณิตศาสตร์ถูกสร้างขึ้นเพื่อลดต้นทุนการขนส่งรวมถึงค่าปรับที่เกี่ยวข้องกับสวัสดิภาพม้าที่ไม่ดี ตัวแปรการตัดสินใจ ได้แก่ ประเภทของรถขนส่งและจำนวนม้าที่ขนส่งในรถขนส่ง โมเดลนี้ใช้งานได้ง่ายและได้รับการตอบรับอย่างดีจากเจ้าของม้า ซึ่งสามารถเลือกรูปแบบการขนส่งที่เหมาะสมที่สุดสำหรับม้าของพวกเขา

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Siengsaw Lertratanachai : A DECISION MAKING MODEL FOR HORSE TRANSPORTATION . Advisor: Assoc. Prof. CHAIPAT LAWSIRIRAT, Ph.D. Co-advisor: Assoc. Prof. Dr. Metha Chanda, Ph.D.

This study developed a mathematical model to select the most appropriate mode of equestrian horse transportation, which balanced between the costs of transportation and horse welfare. The study was divided into two stages. The first stage compared the stress level of transported horses using cortisol as well as heart rate, while the second stage developed a mathematical model that balanced horse health and transportation cost. This research used six horses that were transported by different types of vehicles, i.e., air-conditioned or non-air-conditioned, with or without space, trucks, and trailers with or without space. The horses were transported for 5 hours, covering about 250 kilometers. Horses were transported twice a week for three weeks. The cortisol level and heart rate were collected. The results showed that different modes of transportation resulted in different levels of stress in horses. A mathematical model was constructed to minimize transportation costs as well as penalty costs associated with poor horse welfare. The decision variables included the type of transportation vehicle and the number of horses transported in the transportation vehicle. The model was easily implemented and well received by horse owners, who were able to select the most appropriate mode of transportation for their horses.

Field of Study:	Sports and Exercise Science	Student's Signature ....
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Siengsaw Lertratanachai

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Chapter 1 : Introduction

Equestrian is a sport that involves multiple aspects that are not just ‘horses’ and ‘riders.’ The sport needs good knowledge, understanding, communication, and management of horses, as well as strong bond between horses and riders. With these factors, both can become a ‘combination’, which refers to the relationship between human and animal, the FEI (Fédération Equestre Internationale, the governing body of international equestrian sport) stated the as ‘Two Hearts’ (F. É. Internationale, 2011-2019b). These relationships have been described as complex and interactive (Visser et al., 2003; Wipper, 2000). The relationship between the combination will be tested in competition under the rules and criteria in various levels, ranging from leisure to professional (Dashper, 2016). The sport worldwide is run under the rule of Federation Equestre Internationale (FEI). The majority of the world’s horse population participate in various disciplines such as Dressage, Show Jumping, Eventing (Three Days Event), Horse racing, Endurance, Reining and other leisure activities. There are many competition venues around the world, each create to suit different types of equestrian discipline. The competition venues are located in different places all around the world, in which each competition venue is set to suit different type of equestrian discipline that they are hosting. For example, Eventing needs 3.64 - 6.84 kilometers of competition ground, therefore these competitions are likely to be organized in rural areas (F. E. Internationale, 2018). Since it is rare that competitions will be held at home stable, therefore horse transportation becomes an important aspect in pre-competition preparation. Horse transportation occurs both nationally and internationally (Leadon, Waran, Herholz, & Klay, 2008)Horses need to be transported suitably to minimize risks of accident and effects on horse performance.(Friend, 2001). Due to the fact that the performance in each combination relies on partnership between horse and rider; horse’s mood and welfare; and their both athlete’s health condition (Wipper, 2000).

It has been reported that horses are the most frequently transported livestock; the number of horses being transported daily around the world reaches millions. Horses are being transported for several reasons such as competitions, breeding, new stabling, leisure, sale etc.(Friend, 2001; Herholz et al., 2008; Padalino, 2015). In today’s high-standard competitions and welfare rules and regulations, horses need to maintain their top condition to perform. (Cayado et al., 2006). Many factors affect the maintenance of horse condition in training, pre-competition, during competition and post-competition. Horses have to be exposed to a variety of stress factors which arise from how each has been raised, adjusted dietary, handling, hard physical training session, stabling condition and the harshness of transportation and competition (Friend, 2001; McClure, Carithers, Gross, & Murray, 2005; Stull & Rodiek, 2000, 2002). Horses are normally exposed to variety of stressful events that could arise from the bringing up of each horse, dietary changes, physical training, stabling conditions, as well as handling during transportation and competition.

Transportation has become an important part of pre-competition and post-competition process because it can significantly affect the horse's health, welfare, and performance. During the transportation journey, the potential stressors for horses are derived from combinations of physical factors, psychological stressors, climate factors, and the horse's health status. Firstly, physical factors include distance , duration, space, noise, and road conditions. Secondly, psychological stressors consist of social regrouping and an unfamiliar environment. Thirdly, climatic factors involve air temperature and relative humidity. Finally, all of these factors lead to the risks of horse's health problems during transportation (Stull & Rodiek, 2000). The results caused by transport are usually increase in stress responses through cortisol release, negative effects on respiration and gastrointestinal systems, increased heart rate, higher energy expenditure, and negative effect on the horse's performance. This does not happen to every horse that traveled or could happen to the same horse on a different journey; this also depends on each experience and different factors involved (Art & Lekeux, 2005; Marlin & Nankervis, 2002).

The growing number of equestrian competitions around the world increased horse transportation (A Schmidt et al., 2010). To transport horses, several approaches can be taken such as traveling by sea, land, and air. Horses can be transported by ship, railroad, road, or by aircraft (Waran, Leadon, & Friend, 2007). In the mid-19th century, ships and railroads (traveling by train) are most popular and most commonly used in transporting horses as they are one of the cheapest procedures. However, the downside of these is that they are usually a long, rough, and uncomfortable travelling journey for the horses, which increase risk of injuries. Hence transportation by ships and trains declined significantly (Giovagnoli, 2009; Judge, 1969). Nowadays, the most frequent type of horse transportation is by road using horse-trailers and horse trucks. It is the most reasonable and convenient procedure for moving horses to different places. Horse trailers and trucks are specially designed to comfort the horses to minimize stress, and reduce the risk of injuries during the trip (Waran et al., 2007). On the other hand, traveling by air has been used for international movement of horses. Aircraft transportation has become a common means of transportation nowadays because it is not time-consuming (speed for the long journey) and the journey appears to be very comfortable for the horses. However, this method is also the most expensive type of transportation (Munsters, de Gooijer, van den Broek, & van Oldruitenborgh-Oosterbaan, 2012). Apart from the problem that transportation possibly affects the horse's physical conditions, it also leads to a change in the horse's mental health. Moreover, recent study claims that transportation generated increase in cortisol release and causes changes in heart rate and heart rate variability, which indicates stress in transported horses (Alice Schmidt et al., 2010).

Horse transportation management for equestrian sport is one of the most important factors due to that equestrian sport is the only sport in the Olympic Games which involves animal, horses. The FEI general stated in the horse welfare that "during transportation, horses must be fully protected against injuries and other health risks, the vehicles also need to be safe, well ventilated, maintained to a high standard and driven by competent personnel. Handlers must always be present to manage the horses" (F. E. Internationale, 2019). It is very important to manage horse transportation and all the resources to meet standards. To transport horses to different places all around the world, whether for competitions, breeding, new stabling, leisure activities, or for sale, good preparation and management are essential.

Considering the use participation of horses in equestrian sport, the athletes and responsible people are likely to select the most suitable and reasonable protocols for managing their horses, both in terms of training and transportation in order to maintain their the combination's top performance and reduce risk of injuries and stress before the competition. Duration of the journey, comfortable environment, effect on the performance, and cost of the transportation are factors that athletes or responsible people will seriously take into consideration for managing the transportation. Therefore, they will choose be prone to implement the most effective way of transportation based on a reasonable expense. Horses are considered the second athlete in the combination so they need to be transported with the most suitable transportation method to ensure that they will be in a suitable, comfortable condition and can maintain excellent performance before the start of the competition. Management of the transportation is one of the most important parts of preparation for equestrian combination in the competition. Moreover, suitable transportation would bring the horses being back home safely. On the other hand, poor management of transportation may result in serious injury of horses or compromise the well-being of the horses after the competition.

Due to many reasons that affect the horses' performance and welfare during transportation, it is worth noting that unpredictable problems may occur in horses during usual transportation. The most suitable procedure for horse transportation should be taken into consideration in order to preserve horse welfare. However, scarcity of reports on the effects of different types of vehicles along with the management method for horse transportation, causing no criteria for selecting the most suitable transportation protocol for horses in Thailand. Therefore this study aims to develop a decision-making model to find an appropriate method for horse transportation in Thailand. The decision-making was considered based on two factors; changes in biological parameters in response to different types of transportation and transportation expense. This information was simultaneously evaluated to develop the most acceptable horse transportation model for horse owners in Thailand.

Research question

1. What are the effects of horse transportation vehicle on horse's welfare?
2. Which mode of horse transportation should be selected in order to balance between horse welfare and transportation costs?

Scope of the study

There are two studies in this research project. The first part of the study deals with predicting horse welfare from horse parameters and the second part of the study deals with model construction.

Study I – Study of horse physiology variables during transportation

In Study I, the predicting horse welfare from horse parameters include the independent variables, dependent variables and controlled variables as follows;

The independent variables of Study I include;

Type of transportation vehicle:

1. Horse Air-Conditioning Truck (x_1): Capacity 6
2. Horse Non-Air-Conditioning Truck (x_2): Capacity 8
3. Horse Trailer (x_3): Capacity 2

The variable that effects the biological parameter (behavior) to horses:

Baseline parameter in the study;

1. Horse's biological data, including age, breed, types of exercise, former equestrian participation and previous medical and surgical treatment
2. Body temperature (°C)
3. Heart rate (beats per minute; bpm)
4. Respiration rate (times per minute; tpm)
5. Gut sound (quality of gut motility)
6. Dehydration status (%)
7. Capillary refilling rate (per second)
8. Cortisol level. (μg/dL)

Biological variables of horses in response to road transportation with different types of vehicles.

1. Real-time heart rate detection
2. Cortisol level (μg/dL)
3. Horse's behavior after transportation

The dependent variables of Study I, will be horse welfare for each type of transportation vehicle.

The controlled variables of Study I include:

1. Horse: Equestrian Horses aged above 8 years old that compete in the national and/or international event. As 8 years old equestrian horses is stated by FEI as the minimum aged requirement of horses competing in the national and international championship.
2. Travelling Distance: Horses have undergone non-stop transportation with different vehicle types starting from the Horse Lover's Club, Pathum Thani province, Thailand, and finally returning to the origin. The total distance account for 250 kilometers with approximately 5 hours of travelling time. The transportation was performed by the experienced licensed driver.

Study II – Mathematical Model for Horse Transportation Development

The second study dealt with how mathematical model was created to find the most suitable equestrian transportation that optimized between horse risk and transportation costs. The definitions of terms used in the second study were as follows:

1. Equestrian horse; can be defined as the horse that competed in the field of Dressage, Show Jumping and Eventing which run under the rule of Federation Equestre Internationale (FEI – International Equestrian Federation)
2. Horse Air-Conditioning Truck; The truck, which allows the horses to stand with 90 degrees positions against the length of the vehicle, is capable of loading up to 6 horses. The truck is equipped with an air-conditioning system inside the loading space.
3. Horse Non-Air-Conditioning Truck; The truck, which also allows the horses to stand with 90 degrees positions against the length of the vehicle, is capable of loading up to 8 horses. . The truck, without air-conditioning system installation, permits the natural air to flow through the loading space.
4. Horse Trailer; The trailer, that is towed by a car, can accommodate up to 2 horses in the loading space. The horses stand parallel to the length of the vehicle during the transportation, The trailer permits the natural air to flow through the loading space.
5. Horse's welfare; horse's welfare is defined as the condition in which an individual horse is free from fear, pain, hunger, torture, uncomfortable or other pain that causes the horse to change into worse behavior. FEI stated in the code of FEI that horse condition must be fit to compete.
6. Horse's biological data; the biological data include age, sex, breed, weight, behavior which will identify each horse.
7. Body temperature; the horse's body temperature; the normal body temperature is 37-38.5°C
8. Heart rate; the horse's heart rate could be a reliable parameter to depict stress conditions in horses during road transportation. The normal heart rate in horses is approximately 28-40 beats per minute
9. Behavior observation; Horse behavior was recorded by the surveillance camera after transportation with different transport vehicles. The behavior expression was scored according to the published scale of horse behavior to indicate the stress level in response to stress stimuli.
10. Stress condition; The condition that causes discomfort in horses leading them to show unusual behavior or negatively biological responses.
11. Cortisol; the cortisol hormone produced in living organisms, which is most commonly released when the horses are exposed to stress stimuli. The cortisol level was reportedly changed in response to stress condition and have been using as a parameter to assess the level of stress in animals.
12. Respiratory rate; the horse's respiration rate; normal reparation rate is 8-32 times per minute

13. Gut sound; the gut sound, examined using a stethoscope, is the parameter that quantifies the normal function of the digestive tract. The horse must show a normal gut sound denoted by the thundering sound or sound of water flowing through a pipe. These outcomes indicate satisfied gut motility.
14. Dehydration status; The status to quantitate the level of body fluid deposition. The pinch test, performed by grasping the loose skin at the neck or shoulder and letting it immediately return to normal position, was utilized to depict the normal hydration status.
15. Capillary refilling time; the test is used complementary to the pinch test to estimate the dehydration status. The test is performed by firmly pressing and releasing the thump on the gum to detect the capillary refilling rate. The refilling time to return pink gum less than 2 seconds indicates normal hydration status.
16. Internal temperature; the internal temperature of the vehicles during the transportation
17. Internal humidity; the internal humidity of the vehicles during the transportation
18. Speed and time; the speed and time consuming of traveling from the origin to the destination during the experiment.
19. Distance travel; the distance that the vehicle travel from the origin to the destination of the trip. The experiments were carried out by non-stop transportation on the highway utilizing different vehicle types. The total distance of each experiment was approximately 250 kilometers starting from and returning to The Horse Lover's Club, Patum Thani, Thailand.
20. Fuel expenses, express way and other extra costs involved in the transportation; the cost of gasoline and another extra cost that were met during each transportation.

Benefits of the study

1. To find the effect of stress status in different transportation vehicle types and capacity
2. To find the suitable transporting vehicle for horses to minimize the risk of injury and health issue
3. To create a mathematical model to use for decision making in choosing vehicle to transport horses

Chapter 2 : Literature Review

In this study of a decision-making model for horse transportation, the researcher has research information to guideline this study by revising the related research as follows;

1. Equestrian and horse health status
2. Type of vehicle
3. The effect of the internal and external environment of the vehicle
4. The effect of pre-competition transported and distance travel
5. The potential effect of horse transportation on exercise performance of horses
6. Factors influencing the welfare of the transported animal
7. The effect of transportation on livestock during the transportation to a slaughterhouse
8. Math model

Equestrian and horse health status

Equestrian is the sole sport that combines the athleticism of both humans and animals in global sport recognition such as the Olympic Games. Equestrian first appearance in 1912 at Stockholm Olympic Games with three foundation discipline which involved Dressage, Show Jumping, and Eventing. Later on, Para-Equestrian Dressage also has been added into the Paralympic cycle. In 1921 International Federation for Equestrian Sports (Fédération Équestre Internationale, FEI) has been established as the international governing body of equestrian sport and responsible for all equestrian competition around the globe, equestrian sport competition has run under the FEI code of conduct for competition protests the horse welfare, both physical abuse or doping. The FEI involved eight disciplines with three Olympic and one Paralympic disciplines which are Dressage, Show Jumping, Eventing, Para-Dressage, and four-non-Olympic discipline which are Endurance, Driving, Reining and Vaulting. The minimum age of horse for Eventing discipline required ages above 6 years old; for Showjumping discipline required ages above 8 years old; for Dressage discipline required ages above 8 years old (F. É. Internationale, 2011-2019a). The horses that participated in the competition should have the normal health condition as follow; (Colahan, Mayhew, Merritt, & Moore, 1991)

1. Heart rate (HR) = 28-40 bpm
2. Respiration rate (RR) = 8-32 tpm
3. Body temperature (T) = 37-38.5°C

4. Normal gut sound
5. Dehydration status <5%
6. Capillary refilling time <2 sec

Type of horse transportation vehicle

In this study we will be focusing on road transportation, there are three main types of vehicles for horses transportation in Thailand. Which are horse trailer, horse non-air-conditioning system truck, and horse air-conditioning system truck. These vehicles are mostly owned by private clubs and the cost for different means of transportation are varies depending on the kilometer they wish to travel. The cost for transporting horses at 250 Kilometers; for horse trailer, rated 115 USD – 230 USD per horse, for horse non-air-conditioning truck cost rated 110 USD – 125 USD per horse and for horse air-conditioning truck cost 90 USD – 230 USD per horse (Personal Communications, 2019).

Horse trailer:

The horse trailer used in this experiment (Figure 1) is built with a standard design containing a ramp, rubber floor place in the metal structure, and horse partition divider (Figure 2). The interior condition is designed to fit two horses in the position standing heading towards the traveling direction and towed by a car or van.

Figure 1: The exterior design of the Horse Trailer used in this study.

Figure 2: The ramp and the interior design of the Horse Trailer, which also shows the horse partition divider inside the Horse Trailer.

Horse Non-Air-Conditioning truck:

The Non-air-conditioning truck is designed to fit six horses containing a ramp, rubber floor placed on the metal structure, and horse partition divider with the interior design of the horse position facing 90 degrees against the length of loading space. The exterior design of the Horse Non-Air-Conditioning truck is shown in Figure 3 and the interior design of the Horse Non-Air-Conditioning truck is show in Figure 4.

Figure 3: The exterior design of the Horse Non-Air-Conditioning truck.

Figure 4: The interior design of the Horse Non-Air-Conditioning truck that shows the horse partition divider inside the truck.

Horse Air-Conditioning truck:

The truck installed with the air-conditioning system (Figures 5 and 6) is designed to fit six horses containing a ramp, rubber floor place on the metal structure, and horse partition divider (Figure 7-9). The horse's standing position is 90 degrees against the length of the loading box similar to the non-air conditioning vehicle.

Figure 5: The exterior design of the Horse Air-Conditioning truck.

Figure 6: The ramp and the interior Horse Air-Conditioning truck.

Figure 7: The interior of the Horse Air-Conditioning truck, which show horse partition divider and air-conditioning inside.

Figure 8: The ventilation system on the roof of the truck and windows inside the air Conditioning truck.

The effect of the internal and external environment of the vehicle

The environment inside and outside the horse trailer is a critical aspect especially temperature, humidity, and ventilation inside the trailer. The thermal comfort of the horse does not only depend on the temperature but also depend on humidity (Purswell, Gates, Lawrence, & Davis, 2010). In recent report proof that trailers are unventilated at all speeds (13 to 90 Km/hour) and the trailer has not been adjusted since then (Purswell et al., 2006). The thermal environment is well assessed for other livestock but has not been defined for horses. The thermoneutral zone that is estimated to be suitable for the trailer by the Federation Equestre Internationale (FEI) is in the range of 25°C - 30°C and the upper limited index set for horses in competition is 28°C. However, there are still problem with the inside temperature of the trailer which exceed the limit due to the limited area in the trailer (Purswell et al., 2010). Therefore, horses are not suggested to travel on hot and humid days. Also, the horses should not travel by trailer when the outside temperature exceeds 30°C particularly in hot and dry countries (Mitchell & Kettlewell, 2008). To solve the problem of the temperature inside-to-outside, the trailer has been adjusted to decrease the temperature by increasing the speed of the vehicle travel (Purswell et al., 2010). Furthermore, the design of the interior of the horse trailers and trucks are reconstructed to improve and suit the thermal comfort and ventilation comfort for horses. Trailers and trucks have been added in an adequate ventilation system, window area, increasing the height of the vehicle and adding in fans. This will lead to a decrease in the risk of heat stress

(Mitchell & Kettlewell, 2008). Apart from the effect from inside the trailer and truck, the physical factors outside the trailer and truck also play a major role, which involves trailer motion, noise, the driver's ability, and road condition (Jones, 2003).

The effect of pre-competition transported and distance travel

Horses have been transported for many reasons, many horses nowadays are being transported especially for competition performance purposes. It has been reported that experience horses often have less effect on the performance after being transported over a short distance (D.E. Beaunoyer, 1987). Horses with less experience may face a major stress effect which may lead to a reduction in the horse's performance (Covalesky, Russoniello, & Malinowski, 1992). Longer distance travel also causes an effect on both experience and inexperience horse's stress factors, heart rate, and heart rate variability (A Schmidt et al., 2010). Other research has also been examined that a 194 Km journey could negatively cause an effect of horse performance and slight stress when traveling in a standing position facing towards the direction of the road (Slade, 1987).

The potential effect of horse transportation on exercise performance of horses

Since the limited space to accommodate horses, novel surrounding environment, predisposing the horse to contract new pathogen, water, and feed deprivation, and standing instability of horses during road transportation often cause stress and interfere with the homeostasis of horse (Friend, 2001). It alters several enzymes and hormones' activities, for example, haptoglobin (Hp), serum amyloid (SAA), fibrinogen (Casella, Fazio, Giannetto, Giudice, & Piccione, 2012). Several parameters have been adopted to indicate stress in the horse. Heart rate (HR) and cortisol level were reportedly change in response to stress condition (Visser et al., 2002; Young, Creighton, Smith, & Hosie, 2012). An increase in HR was noticed in the horse during the first trailer loading training session (Hendriksen, Elmgreen, & Ladewig, 2011; Keeling, Jonare, & Lanneborn, 2009) and the transportation (Alice Schmidt et al., 2010). Moreover, the saliva cortisol level was also increased in horses exposing the stress conditions (Young et al., 2012). In addition, cortisol levels increased in both saliva and fecal cortisol during road transportation (Alice Schmidt et al., 2010). The stress condition also exerts an influence on the hematology of the animals. It was reported that haptoglobin (Hp), and serum amyloid (SAA) increase significantly as the acute phase response to stress during transportation (Crisman, Scarratt, & Zimmerman, 2008). Interestingly, an increase in white blood cell (WBCs) number were found in calve in response to transportation stress but did not indicate the susceptible to disease (Buckham Sporer, Weber, Burton, Earley, & Crowe, 2008; Earley & O'Riordan, 2006). Several enzymes, hormones, and HR can use as an indicator to predict the stress condition of the horse during transportation.

Factors influencing the welfare of the transported animal

The welfare of an animal during transportation is assessed by behavioral factors and physiological factors. Health status is an important factor for animal welfare evaluation. Various indicators were used to measure the health status of an animal during transportation such as stress responses, long-term adverse effects on body condition, pain, fear, and other uncomfortable condition that negatively impact health status. In addition to the health status, the attitude and the driver experience also impact the animal's welfare during transportation. (Grandin, 2014)

The effect of transportation on livestock during the transportation to a slaughterhouse

The study of critical points for transporting cattle to a slaughterhouse in Spain during the loading, transporting and unloading. The result shows that the difficulties of loading depend on the cattle breed, some breeds of cattle are more difficult to handle and more get more nervous than other breeds. The unloaded process at the slaughterhouse takes a short period and the cattle are unloaded in a group. During transportation, the animal stood in the correct way facing the direction of the road rather than in a different direction. The changes in the stable environment such as getting into the transporting vehicle over a short period during the travel cause the effect on the animal stress sensor, physical parameter damages, and cause injuries. The high Spain summer temperature (40-45°C) may cause the animal to be dehydrated which leads to a decrease in the quality of the meat (Villarroel et al., 2001). The transportation of cattle could lead to several negative effects, including poor quality of the meat due to weight loss, dehydration, high body temperature, increase in heart rate, higher respiration rate, increasing blood cortisol level, changes in pH, and the injuries during the transportation (Knowles, 1999).

Mathematical model

Mathematical optimization including numerical techniques such as linear and nonlinear programming, integer programming, network flow theory and dynamic optimization has its origin in operations research developed in World War II, e.g., Morse and Kimball 1950 [45]. Most of the real-world optimization problems involve multiple conflicting objectives which should be considered simultaneously, so-called vector-optimization problems. The solution process for vector-optimization problems is threefold, based on decision-making methods, methods to treat nonlinear constraints and optimization algorithms to minimize the objective function. Methods for decision-making, based on the optimality criterion by Pareto in 1896 [48], have been introduced and applied to a wide range of problems in economics by Marglin 1966 [42], Geoffrion 1968 [18] and Fandel 1972 [12]. The theory of nonlinear programming with constraints is based on the optimality criterion by Kuhn and Tucker, 1951 [37]. Methods for the treatment of nonlinear constraints have been developed by Zoutdendijk 1960 [70], Fiacco and McCormick 1968 [13] and Rockafellar 1973 [54] among others. Numerous optimization algorithms both using deterministic and stochastic elements have been developed in the sixties and covered in the books by Wilde 1964 [67], Rosenbrock 1966 [55], Himmelblau 1972 [25], Brent 1973 [5], and Schwefel 1977 [62]. Researchers tend to come back to genetic and evolutionary algorithms recently as they are suited for parallel processing, finding global optima, and are reported to be suitable for a large number of design variables Fogel 1994 [15], Holland 1992 [26]. Mathematical optimization techniques have been applied to computational electromagnetics already for decades. Halbach 1967 [23] introduced a method for optimizing coil arrangements and pole shapes of magnets by means of finite element (FE) field calculation. Armstrong, Fan, Simkin and Trowbridge 1982 [2] combined optimization algorithms with the volume integral method for the pole profile optimization of a H-magnet. Girdinio, Molfino, Molinari and Viviani 1983 [20] optimized a profile of an electrode. These attempts tended to be application-specific, however. Only since the late 80 th, have numerical field calculation packages for both 2d and 3d applications been placed in an optimization environment. Reasons for this delay have included constraints in computing power, problems with discontinuities and nondifferentiabilities in the objective function arising from FE meshes, accuracy of the field solution and software implementation problems. A small selection of papers can be found in the references. The variety of methods applied shows that no general method exists to solve nonlinear optimization problems in computational electromagnetics in the same way that the simplex algorithm exists to solve linear problems. There are many different applications in computational electromagnetics and each one requires its own particular procedure. Some optimization procedures are described in the following sections that have been proven efficient for problems in computational electromagnetics and are provided for general use in the ROXIE program.

Methods of decision-making Applying mathematical optimization routines requires a decision-making method that guarantees a solution from the Pareto-optimal solution set. Below some methods are described that have been applied to computational electromagnetics, author’s papers [56], [57]. A comprehensive overview can be found in Cohon

Linear programming is used for decision making, for managing the limited natural resources for the best benefit, it always has the objective to maximize or minimize something. Especially for manufacturing companies, on the management of the raw product to maximize the profit and minimize the cost of production. In order to maximize the profit and minimize the cost of production the variables and limited conditions that need to take in considerate for finding the equation would be the quantity of the manufactured product, profit, duration of the manufacturing, and cost of production (Vanderbei, 2001).

Researches on livestock and animal transportation showed the importance and effects of transportation on animals. Transportation affects the mental state of animals due to changes in the environment which may lead to stress and negatively affect the meat quality of livestock. Though there are several pieces of research relating to the transportation of livestock and animal, none has addressed how the mode of transportation for the horse is selected. The proper mode of horse transportation results in horse readiness, horse welfare, and economy. Therefore, in this study is aim to investigate the effects during the transportation on the different types of vehicle, problems and create a mode selection model that suitable for horse transportation, to maximize horse welfare and minimize transportation cost.

Conceptual Framework of the study

The independent variables of this research are the different types of horse transportation methods. Which are air-conditioning truck, non-air-conditioning truck, and car-driven trailer. The biological data were collected and the parameters were quantitated in response to the transportation using different types of vehicles. All data, including all expenses related to transportation, were further analyzed to indicate the proper transportation method, and finally established the decision-making model for the acceptable transportation method.

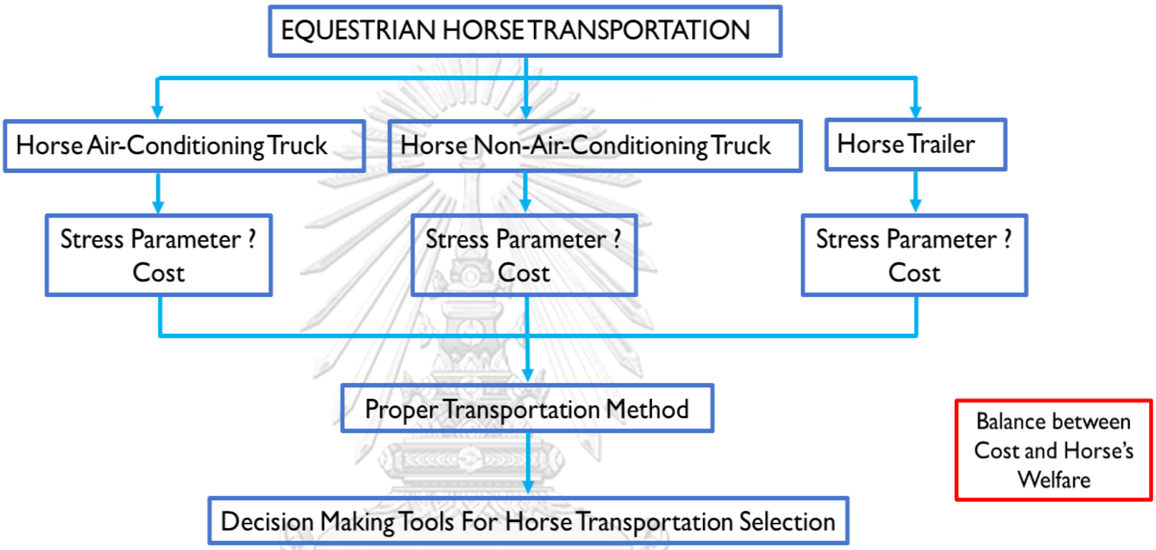


Figure 9: The conceptual framework of the study.

Chapter 3 : Study of horse physiology variable during transportation

Road transportation was a practical method to bring the horse to the venue during local competition season. Due to the fact that loading the horse into a limited space within the vehicle may cause a change in stress responses in horses thereby compromising the welfare of the horse during the transportation. The physiological parameters, including heart rate and blood cortisol level must be taken into account and could be altered accompanying the road transportation.

Materials and Methodology

Data Collection

Before the study commenced, baseline biological data of all horses, including body temperature, gut sound, respiratory rate, heart rate, dehydration status, capillary refilling rate, and cortisol level at rest were determined. Heart rate was determined in real-time starting from 10 minute before the movement and lasting till 90 minutes after the end of transportation. Speed of the vehicle, transportation distance, transportation period, internal humidity and temperature were continuously recorded throughout the transportation period. Cortisol levels were detected before the transportation, immediately after transportation, 30 minutes, and 90 minutes after transportation. Horse behavior was observed for 90 minutes after transportation. Cost of gasoline and other extra cost involved in the transportation were also recorded in this study. Collect data and samples to analyze data to find the appropriate transportation method for equestrian horse that balance between horse's welfare and transportation cost.

Subjects of the study

Due to limited space for accommodating the horses in the truck corresponding to the sample size calculation from the statistic program (Minitab), six healthy athlete horses (aged 8-15 years old, weighed 400 to 500 kilograms) from the Horse Lover's Club were recruited in this study. All horses show normal vital parameters including heart rate, respiratory rate, gut sound, dehydration status, capillary refilling time, and body temperature before the study. They were housed in separated stables on either straw or rubber patch bedding and fed with commercial pellet feed three times daily, pangola hay and water are provided ad libitum. All horses have undergone a similar exercise training regimen assuming that they were in the same fitness level.

In brief, the horses performed light to moderate-intensity exercise for 2 hours daily and grazed in the paddock 1-2 hours daily. They were allowed to relax in the paddock for up to 4 hours daily on the day off.

Collection of data and samples

The method and indicators use in collecting horse data, samples and parameter is show in Table 1. The method of collecting vehicle data is show in Table 2.

Table 1: show the six equestrian athlete horse sample and parameters collection method

Physical health status: Samples and parameters collect	**Method used for collecting data**	**Data Collected by**
Horse's biological data age, sex, breed, weight	Information from each horse's passport and horse's weight tape	Licensed Veterinarian
Body temperature	Digital thermometer	Licensed Veterinarian
Heart rate	Stethoscope (before the study) Polar HR monitor (H10) connected to polar sports watch (Vantage 2) (during the experiment)	Licensed Veterinarian
Horse behavior	Behavior scales indicate stress level according to the method described by T. Young et al. (2012)	Five equestrian professionals such as equestrian athletes, coaches and veterinarian.
Cortisol (Stress hormone)	serum samples for cortisol determination using a competitive chemiluminescent enzyme immunoassay (IMMULITE Analyzers; Siemens Healthineers, Erlangen, Germany).	Licensed Veterinarian
Respiration rate	Stethoscope	Licensed Veterinarian
Gut sound	Stethoscope	Licensed Veterinarian

Physical health status: Samples and parameters collect	**Method used for collecting data**	**Data Collected by**
Dehydration status	Pinch test	Licensed Veterinarian
Capillary refilling rate	Pressing finger firmly against the gum then release	Licensed Veterinarian

Table 2: show the vehicle data collecting method

Vehicle data	**Method used for collecting data**	**Data Collected by**
Internal temperature	humidity data logger (HTM-305 U)	Researcher
Internal humidity	humidity data logger (HTM-305 U)	
Speed and time	Polar HR monitor (H10) connected to polar sports watch (Vantage 2)	
Distance travel	Polar HR monitor (H10) connected to polar sports watch (Vantage 2)	
Cost of gasoline and other extra cost involved in the transportation	Payment slip from the gas station	
Departure and arrival date and time	Digital watch and calendar	

Indicator tools for collection of data and samples; Six equestrian athlete horses

1. Body temperature will be measured using digital thermometer SU-MED-013, Successpromo, China by researcher.
2. Heart rate will be measured with stethoscope Sr2211,3m Littmann Classic II S.E. Stethoscope, China by licensed veterinarian.

3. Heart rate variability will be measured individually throughout the duration of transportation using a Polar HR monitor (H10) connected to polar sports watch (Vantage 2)(Polar Electro, Oy, Kempele, Finland). Data will be collected by researcher.
4. Stress observation; horses will be score for changes in horse behavior according to each transportation method using scale of behavioral indicators “Behavior score (BS)” method (Young et al., 2012) by five equestrian professional such as equestrian athletes, coaches and veterinarians. Through watching video recording from internet protocol (IP) camera (MC2MP- 4CW; Goke Microelectronics, Hunan, China) connected to an iPhone XS (A2097; Apple, California, USA).
5. Cortisol (Stress hormone) will be collecting blood and serum samples from jugular vein into blood collection tubes which EDTA tube and without EDTA tube by licensed veterinarian, which EDTA tube and without EDTA tube be provided by Becton, Dickinson and Company, Franklin Lakes, New Jersey, USA.
6. Respiration rate will be measured with stethoscope Sr2211,3m Littmann Classic II S.E. Stethoscope, China by licensed veterinarian.
7. Gut sound will be measured with stethoscope Sr2211,3m Littmann Classic II S.E. Stethoscope, China by licensed veterinarian.
8. Dehydration status will be examined by pinch test on the horse’s neck which will be examined by licensed veterinarian.
9. Capillary refilling rate will be tested by licensed veterinarian by pressing finger firmly against the gum then release. The gum should be light pink and moist and capillary refilling time should be less than 2 seconds.

Horse transportation vehicle

1. Internal temperature and humidity will be collected using humidity data logger (HTM-305 U) temperature and humidity detector, which will be implemented to measure the humidity and environment temperature throughout the duration of transportation.
2. Speed, time and distance travel will be collected using Polar HR monitor (H10) connected to polar sports watch (Vantage 2) (Polar Electro, Oy, Kempele, Finland). Data will be collected by researcher.

3. Cost of gasoline, Express way and other extra cost involve in the transportation will be collected by researcher.
4. Departure date and time will be recorded by researcher.

Method of data and sample collection and experimental protocol

Grouping and gathering the data base of equestrian horses

1. The biological data from six equestrian horses including age, sex, breed, weight, illness history and contest experience are concluded in the database document.
2. The physical examination including heart rate, respiratory rate, capillary refilling time, dehydration status, gut motility and temperature will be recorded as baseline health status of six horses

Transportation method

1. The six horses were repeatedly loaded and transported from the Horse Lover's Club, Patumthani province, Thailand, and returned to their origin on the same date. After each loading, they were allowed to rest for at least 48 hours before the consecutive experiment.

The initial experiment was to evaluate the changes in the biological and physical parameters in response to transportation by both vehicles with and without air conditioning. All six horses were transported via air conditioning vehicle on the first date and swap to the non-air conditioning vehicle on an alternate day. Figure 11, Figure 13, Figure 14, Figure 15, Figure 17 and Figure 18 show the position of the horse loading standing during the first date and the alternate experiment.

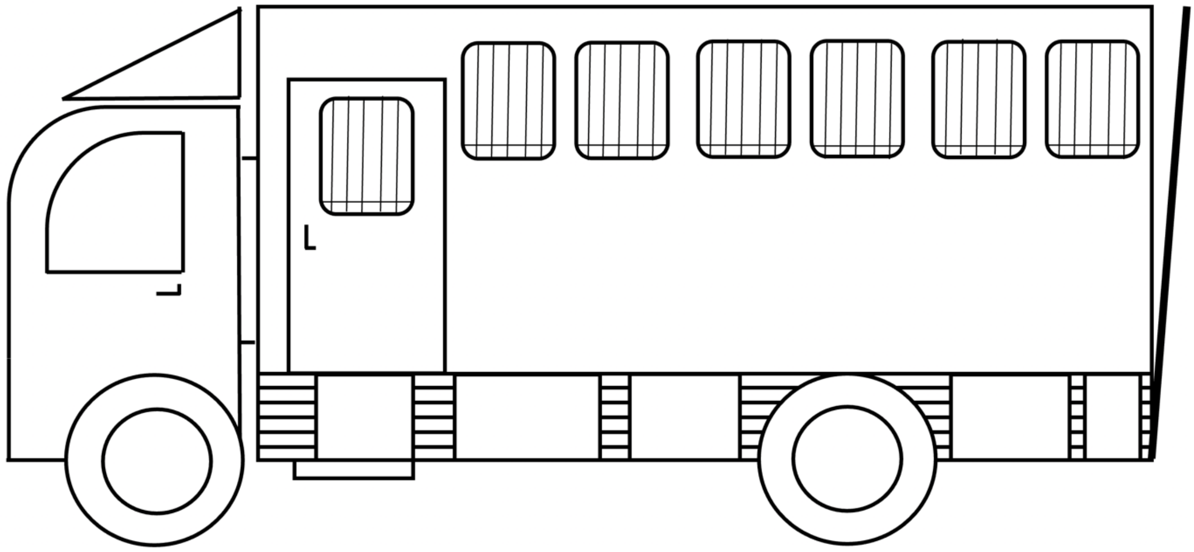


Figure 10 – Diagram of air-conditioning truck

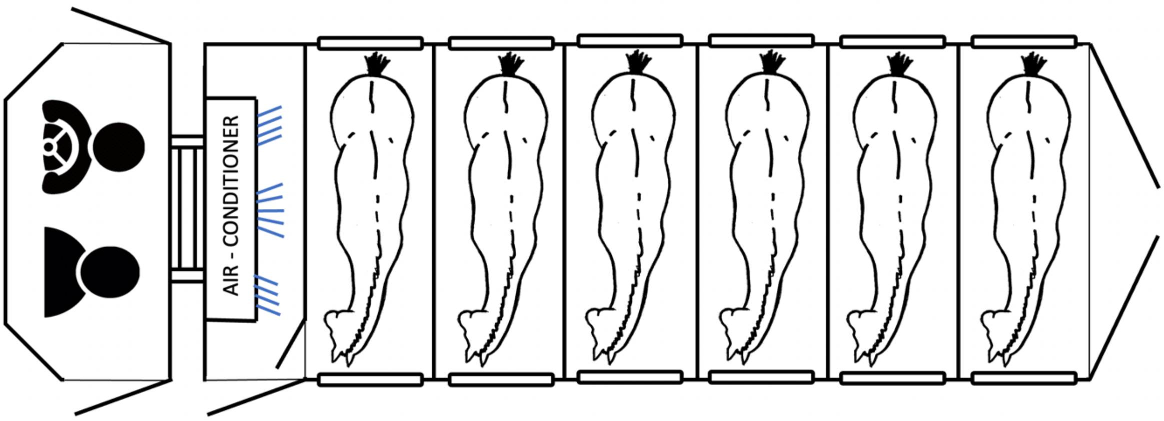


Figure 11 – Diagram show the position of the horses standing during the full capacity air-conditioning experiment

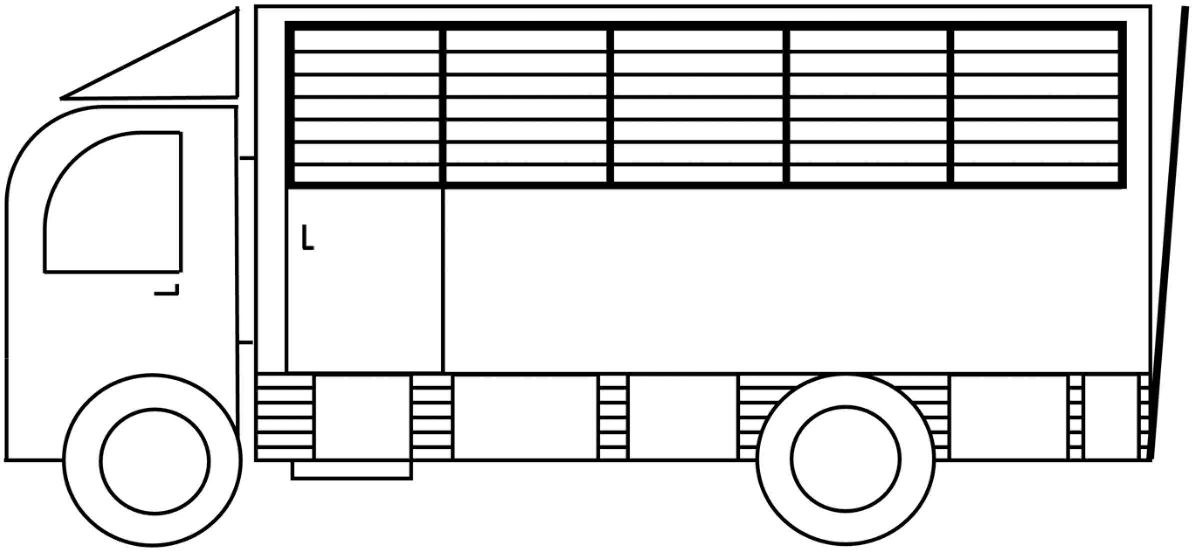


Figure 12– Diagram of non-air-conditioning truck

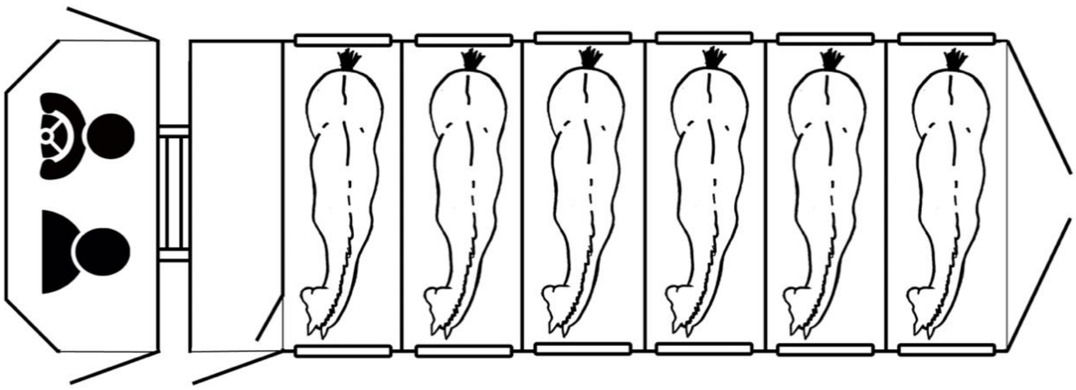


Figure 13– Diagram show the position of the horses standing during the full capacity loading non-air-conditioning experiment

The second experiment was to evaluate the loading with space on biological and physical parameters in response to transportation by both vehicles with and without air conditioning. On the first date of the second experiment, a group of three horses each was transported via either air conditioning or non-air conditioning vehicles on the first date. The horses were swapped to the other vehicles as a cross-over study on an alternate day.

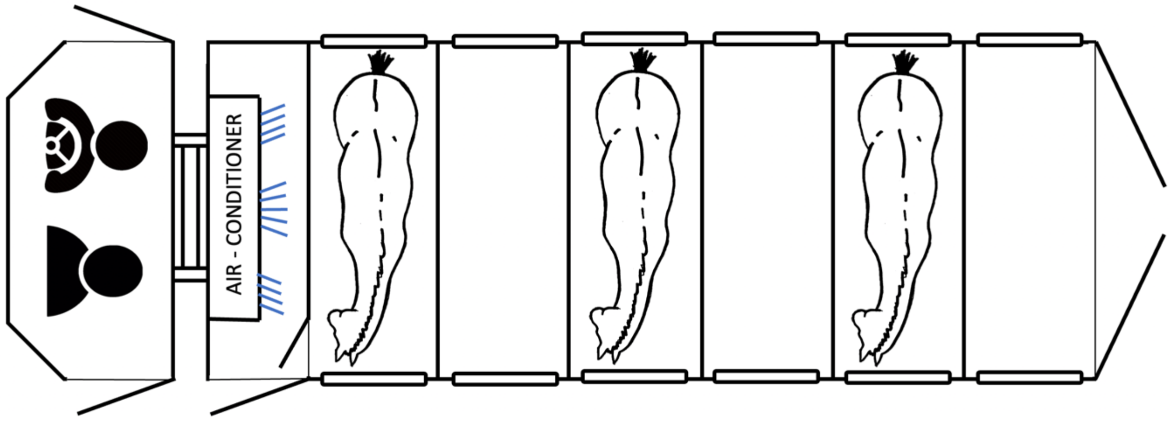


Figure 14– Diagram show the position of the horses standing during the loading of a spacing capacity air-conditioning experiment

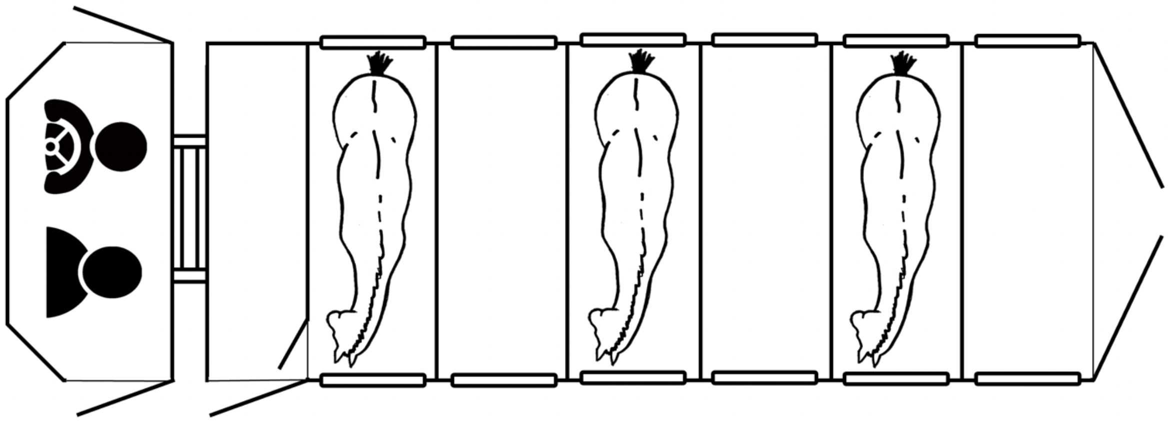


Figure 15 – Diagram show the position of the horses standing during the loading of a spacing capacity non-air-conditioning experiment

The last experiment was to evaluate the changes in the biological and physical parameters in response to transportation by car pulling-trailer. Only three horses participated in the last experiment. Two horses were transported simultaneously via the car pulling-trailer on the first date of the last experiment. The last horse was solely loading on the car pulling-trailer on an alternate day.

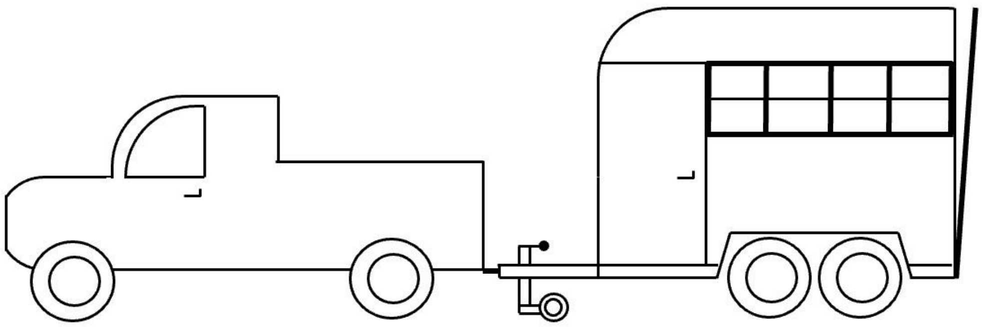


Figure 16 – Diagram of a car pulling-trailer

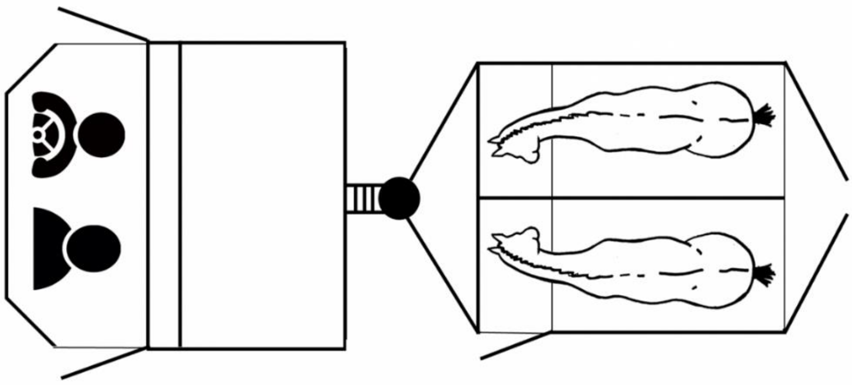


Figure 17– Diagram show the position of the horses standing during the full capacity loading car pulling-trailer

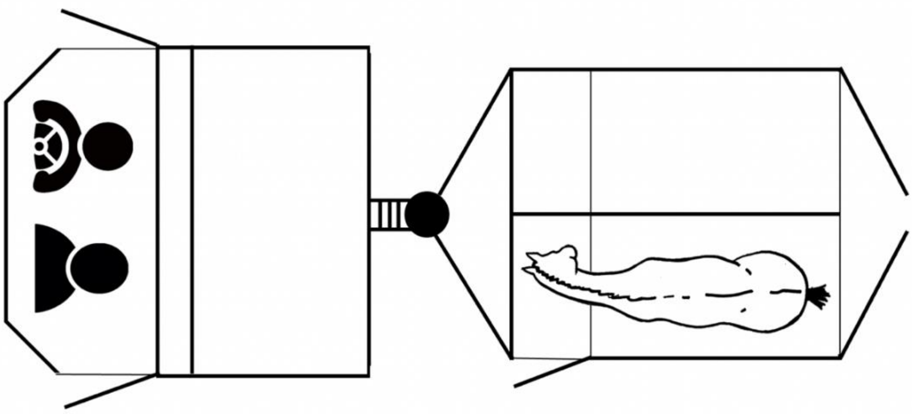


Figure 18– Diagram show the position of the horses standing during the loading of a spacing car pulling-trailer

All vehicles were driven by the experience licensed drivers. The vehicles will be clean and disinfected with an antiseptic solution. Throughout each transportation, the horse will also be given pangola hay. the experiment procedure is showed in Table 3;

Table 3: show the period of different vehicle experiment

<table>
<tr><th>Experiment</th><th>Types of vehicles</th><th>1st Week</th><th>2nd Week</th><th>3rd Week</th></tr>
<tr><td>1</td><td>Horse Air-Conditioning Truck
(6 Horses; Full capacity)</td><td>→</td><td></td><td></td></tr>
<tr><td>2</td><td>Horse Non-Air-Conditioning Truck
(6 Horses; Full capacity)</td><td>→</td><td></td><td></td></tr>
<tr><td>3</td><td>Horse Air-Conditioning Truck
(3 Horses; Spacing capacity)</td><td></td><td rowspan="2">→</td><td></td></tr>
<tr><td>4</td><td>Horse Non-Air-Conditioning Truck
(3 Horses; Spacing capacity)</td><td></td><td></td></tr>
<tr><td>5</td><td>Horse Air-Conditioning Truck
(3 Horses; Spacing capacity)</td><td></td><td rowspan="2">→</td><td></td></tr>
<tr><td>6</td><td>Horse Non-Air-Conditioning Truck
(3 Horses; Spacing capacity)</td><td></td><td></td></tr>
<tr><td>7</td><td>Horse Trailer
(2 Horses; Full capacity)</td><td></td><td></td><td>→</td></tr>
<tr><td>8</td><td>Horse Trailer
(1 Horse; Spacing capacity)</td><td></td><td></td><td>→</td></tr>
</table>

2. The distance of transportation is approximately 250 kilometers and each transportation duration will be approximately 5 hours in returning to the origin. These 250 kilometers distance travel is the distance of the main and most commonly use competition venue that horses are being transported in Thailand. In this study, the researcher does not investigate the effect of distance travel therefore researcher has to set a fixed distance and direction travel for every transported vehicle.
3. All transportation vehicle experiment will departure at similar time with the same distance travel to the same destination and vehicle will be driven by the specialist

licensed driver. The control variables will be six equestrian athlete horses, horse's age, distance travel, method of transportation distance travel and direction, departure and destination venue and data and sample collection method. The confounding variables will be traffic, situation during the transportation and external temperature, but researcher cannot control the confounding variable but will be aware of it. Which these data will be considered and evaluate together with the horse's parameters data. Due to that these data could be or could not be the effect of the changes in horse's parameter. Researcher are collecting data for real situation during each type of transportation vehicle experiment. The data will also be analyzed and involved in future discussion.

The collection of data and samples of the experiment

1. The horses will be examined 30 minutes before being loaded into the transporting vehicle due to the fact that it is the shortest preparation time before being transported if the researcher examined the horses more than 30 minutes before loading. There might create an effect on the horse's stress before being loaded onto the vehicle. This recorded physical examination parameters will be the baseline health status for each individual horse. The Polar HR monitor (H10) connected to polar sports watch (Vantage 2) was equipped 15-30 minutes before the horse was loaded onto the transporting vehicle, the data will be the control data of each horse and finish the measurement 3 hours after the arrival. After the return back to the origin, blood samples were continuously collected immediately after transportation, 30 min and 90 minutes transportation for blood cortisol determination. Due to that it is the period of time where the horse's parameter might have the most changes and it is the assumed time for horses to rest in each period before competition. The set time for the examined period is set to keep track of the changes in horse's parameter after arrival at the destination, it does not matter of how to set the time for collecting data after the arrival because researcher is not studying about the time course that effect the changes in horse's parameters. All the method of collecting horse parameters is show in Table 4.

Table 4: show the period and the information of the parameters collecting method

Time period	Samples and Parameters collecting location	Data Collected by	Physical health status: Samples and parameters collect	Indicator used in collecting data	Data analyzes
30 minutes before loaded onto the vehicle	In the stable	Researcher	1.Body temperature	Digital thermometer	
		Licensed Veterinarian	2.Heart rate	using stethoscope	
			3.Stress observe	(observation)	
			4.Cortisol	Collecting blood and serum samples	Starting value (Baseline value)
			5.Respiration rate	using stethoscope	
			6.Gut sound	using stethoscope	
			7.Dehydration status	pinch test	dehydration status <5%
			8. Capillary refilling time	Finger pressing the gums	Capillary refilling time<2secs
Immediately after unloaded from the vehicle	In the stable	Researcher	1.Heart rate	Using Polar HR monitor (S610i)	
			2.Stress observe	Camera (observation)	scale of behavioral indicators
Immediately after unloaded from the vehicle	In the stable	Licensed Veterinarian	3.Cortisol level	Collecting blood and serum samples	
30 minutes	In the	Licensed	1.Heart rate	Polar HR monitor	

Time period	Samples and Parameters collecting location	Data Collected by	Physical health status: Samples and parameters collect	Indicator used in collecting data	Data analyzes
after unloaded from the vehicle	stable	Veterinarian		(H10) connected to polar sports watch (Vantage 2)	
			2.Stress observe	internet protocol (IP) camera connected to an iPhone XS	scale of behavioral indicators
			3.Cortisol level	Collecting blood and serum samples	
90 minutes after unloaded from the vehicle	In the stable	Licensed Veterinarian	1.Heart rate	Polar HR monitor (H10) connected to polar sports watch (Vantage 2)	
			2.Stress observe	internet protocol (IP) camera connected to an iPhone XS	scale of behavioral indicators
			3.Cortisol level	Collecting blood and serum samples	

2. The horse parameters will be collected as shown:

2.1 Body temperature using digital thermometer: The normal body temperature for horses is 37-38.5°C. The method of using digital thermometer to collect horse body temperature is show in Figure 19.

Figure 19: Measuring the horse temperature using a digital thermometer.

2.2 Heart rate and heart rate variability using stethoscope and Polar HR monitor (S610i) : The horse with normal heart rate is 28-40 beat per minute. The equestrian horses will be individually equipped with the Polar HR monitor during the period of each transportation. The heart rate monitor consists of electrode belt fastened on the horse chest, the electrode belt that was placed 10cm. posterior to left elbow will transmit the electric activity of heart though wireless transmission system to the wrist watch receiver. The real time heart rate variable during the transportation will be recorded and further analyzed for stress condition. The Polar HR monitor will be equipped onto the individual horse 15-30 minutes before loaded onto the transporting vehicle, the recorded data will be the control data of each individual horse and finish the measurement 90 minutes after the arrival. The heart rate variability is to evaluate the significate changes of the heart rate during the transportation, compared to the normal value before the transportation. To measure horse heart rate using stethoscope is show in Figure 12. To measure horse heart rate and heart rate variability using Polar HR monitor (S610i) is show in Figure 21.

Figure 20: The licensed veterinarian measuring the horse's heat rate on the side of a horse using a stethoscope.

Figure 21: The heart rate being recorded using Polar HR monitor (H10)

2.3 Stress observation; The behavior of the horses will be recorded after the transportation period using an internet protocol (IP) camera (MC2MP-4CW; Goke Microelectronics, Hunan, China). The video cameras were installed at the appropriate position in the stables to gain an adequate area of vision. The video cameras were then wirelessly connected to an iPhone XS (A2097; Apple, California, USA) to record horse behavior for stress level evaluation. The six equestrian horses will be individually observed for behavior score to evaluate the stress condition by a panel of equestrian professionals such as equestrian athletes, coaches and veterinarians. (Modified from Young, Creighton, Smith, & Hosie, 2012). A scale of behavioral indicators of stress is shown in Table 5;

Table 5: show the scale of behavioral indicators

Stress level	Behavioral score	Behavioral indicator
No stress	1	Horse calm, unconcerned, relaxed, quiet, listening, accepting
	2	Horse alert and watching
Low stress	3	Listening, interested, alert
	4	Curious, unsettled, barging.
Medium stress	5	Restless, showing tension in the body, fidgeting when still
	6	Jumpy, easily startled
	7	Relentless
High stress	8	Stamping of hind feet, Snorting, very unsettled and alert
	9	Agitated, fidgety, anxious, active, aggressive, uncomfortable

2.4 Sample collection

The horses will be taken whole blood and serum samples before loaded into the transportation vehicle, immediately after unloaded at destination, 30 minutes after the arrival at destination and 90 minutes after the arrival at the destination.

2.4.1 Whole blood and serum samples

10-15 ml. of blood samples are collected from jugular vein, then, divided for 2 containers. 4 ml. of whole blood sample is contained in EDTA tubes and preserved at 4°C for complete blood count and the rest of blood is put into the blood tube without EDTA, after that, the tube is spun to separate the serum and preserve at -80°C for blood chemistry evaluation. Cortisol will be collected by collecting blood and serum samples from jugular vein into EDTA blood collection tube and serum blood collection tube. Cortisol level will be collected before the transport and after the transport to see the changes in the cortisol level. The blood chemistry will be taken before the transportation, immediately after unloaded from the vehicle, 3 0 minutes after unloaded from the vehicle, 90 minutes after unloaded from the vehicle to evaluate the significate changes of each blood chemistry value at the time of sampling, compared to the normal value before the transport. The method of collecting blood samples and EDTA blood tube is show in Figure 22.

Figure 22: illustrates the blood sample collection on the right jugular vein of the horse and placed into the blood tube.

2.4.2 Hematology and blood biochemical analysis

Whole blood samples in EDTA tube will be subjected to analyze the complete blood count. Serum in blood tube without EDTA will be subjected to analyze blood biochemistries including creatine kinase (CK), aspartate transferase (AST), and cortisol level. All blood samples were analyzed using a competitive chemiluminescent enzyme immunoassay (IMMULITE Analyzers; Siemens Healthineers, Erlangen, Germany) The biochemical analysis was performed by the Thai vet lab Co., Ltd., Bankapi, Bangkok, Thailand.

2.5 Respiration rate; horse's flank and rib cage rise and fall as the horse breathe. Count each inhalation (breathe in) and exhalation (breathe out) together as one breath using a stethoscope. The normal horse respiration rate should be 8-32 times per minute. The method to collect data of respiration rate using the stethoscope is shown in Figure 23.

Figure 23: The licensed veterinarian examined the respiration rate on the side of a horse using the stethoscope.

2.6 Gut sound should be normal by listening with stethoscope on each side of the horse's abdomen, above and below the flank area the sound heard can be varied, and should always be able to hear sound in all quarters. The method to collect data of gut sound using the stethoscope is shown in Figure 24.

Figure 24: The licensed veterinarian examined the gut sound on the side of a horse using a stethoscope.

2.7 Dehydration status will be examined by pinch test; take a pinch of skin along your horse's neck

and let it go again, normal horse should present dehydration status <5%. The pinch test to define the dehydration status is shown in Figure 25.

Figure 25: Pinch test; take a pinch of skin along your horse's neck.

2.7.1 Capillary refilling time tested; Gums should be light pink and moist, and capillary refill time less than 2 seconds. The method of testing the capillary refilling time is shown in Figure 26.

Figure 26: Pressed finger firmly against the gum then release, capillary refill time less than 2 second.

2.8 Assessment of horse welfare

The licensed veterinarian will assess the horse welfare using a 5-point Likert scale for each type of vehicle before and after transport.

Environmental factors of the vehicle

The relative humidity and environment temperature will be measured throughout the transportation period using a humidity data logger (TM-305 U; Tenmars Electronics, Taipei, Taiwan). The equipment will be installed in the truck at the appropriate position before the commence of transportation

Experimental protocol

The study is to investigate the change in behavior and stress hormone of equestrian horses in response to the different types of the transport vehicle. The result of the study will be implemented to design a mathematical model for the selection of a suitable transportation method which balances the horse's welfare and transportation cost.

Speed and period of transportation

The horses were transported at a speed of 81-92 km/hour in all experiment. A total period of each transportation was 5 hours approximately

Result

Horse behavior

The behavior scores were 1-2 in all horses during the 90 min period indicating that there was no physical stress after the transportation.

Table 6: Behavioral scores of horses at 90 min after transportation

Horse	Behavioral scores			
	ACVFL	NACVFL	ACVSL	NACVSL
Happy Star K	1	1	1	1
Dakota	1	2	1	2
Audine B	1	1	2	2
Victory B	1	1	1	1
Happy Hour	1	2	2	2
Elmo BB	2	2	1	2

ACVFL; Air-conditioned vehicle with full loading, NACVFL; Non-air-conditioned vehicle with full loading, ACVSL; Air-conditioned vehicle with space loading, NACVSL; Non-air-conditioned vehicle with space loading

Serum cortisol level

Transportation with different types of vehicles

Table 7: Show the blood cortisol level during road transportation by air-conditioned vehicle with full loading

Horse	Blood cortisol level (ng/mL)			
	Before transportation	After transportation		
		Immediately	30 min	90 min
Happy Star K	36	65	46	33
Dakota	42	54	29	22
Audine B	23	33	25	22
Victory B	23	42	29	17
Happy Hour	13	4.7	3.4	24
Elmo BB	14	37	18	15

Table 8: Shown blood cortisol level during road transportation by non-air-conditioned vehicle with full loading

Horse	Blood cortisol level (ng/mL)			
	Before transportation	After transportation		
		Immediately	30 min	90 min
Happy Star K	32	52	40	24
Dakota	32	45	29	16
Audine B	20	30	20	21
Victory B	25	48	36	19
Happy Hour	40	52	38	31
Elmo BB	33	35	25	19

Table 9: Shown blood cortisol level during road transportation by air-conditioned vehicle with space loading

Horse	Blood cortisol level (ng/mL)			
	Before transportation	After transportation		
		Immediately	30 min	90 min
Happy Star K	27	50	33	20
Dakota	28	27	21	11
Audine B	24	34	21	27
Victory B	40	45	30	18
Happy Hour	34	53	36	26
Elmo BB	31	30	18	11

Table 10: Shown blood cortisol level during road transportation by non-air-conditioned vehicle with space loading

Horse	Blood cortisol level (ng/mL)			
	Before transportation	After transportation		
		Immediately	30 min	90 min
Happy Star K	26	53	42	23
Dakota	29	42	27	18
Audine B	22	30	19	12
Victory B	24	46	33	22
Happy Hour	26	52	39	27
Elmo BB	17	33	23	14

Serum cortisol levels in response to different types of transportation vehicles are shown in figure 27. Baseline cortisol levels in horses before transportation were 25.17 ± 4.78 ng/mL, 30.33±2.84ng/mL, and 30.33±3.76 ng/mL for air-conditioned truck, non-air-conditioned truck, and car-pulling trailer, respectively. The cortisol level in horses in both air-conditioned and non-air-conditioned trucks increased immediately after transportation ($p = 0.011$ and $p = 0.26$, respectively) and reduced at 30 min ($p = 0.005$ and $p = 0.0002$, respectively) and 90 min ($p = 0.002$ and $p = 0.005$, respectively) after transportation. Although there was no change in cortisol level immediately in horses after transportation in car-pulling trailer ($p = 0.07$). a reduction in the cortisol level was detected later than the other transportations at 90 min ($p = 0.013$).

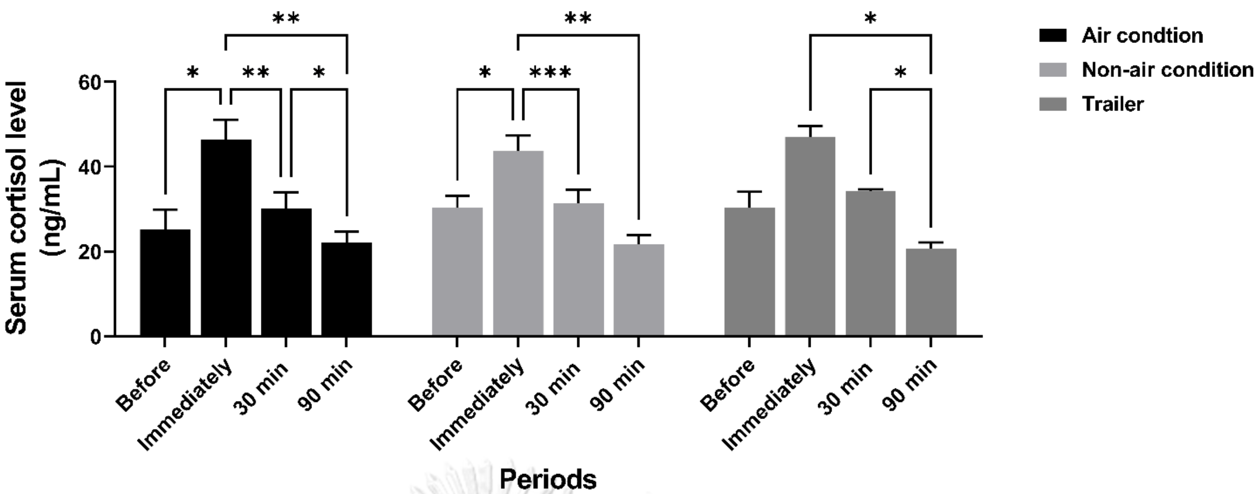


Figure 27: Cortisol level in response to transportation with three different types of vehicles. The cortisol levels were measured at before transportation, immediately after transportation, 30 and 90 min after transportation.

* indicate $p < 0.05$ between pairs of the comparison.

** indicate $p < 0.01$ between pairs of the comparison.

*** indicate $p < 0.001$ between pairs of the comparison.

Transportation with spacing condition

Serum cortisol level during transportation with spacing condition is demonstrated in figure 28 and figure 29. Transportation with spacing in air-conditioned truck cause no increase in cortisol level immediately after transportation (figure 28; right panel); however, a decline in cortisol level was also observed at 30 and 90 min similar to those described in horses transported in air-conditioned truck without spacing (figure 28). On the contrary, spacing produce on effect on the cortisol level as the a similar trend of cortisol alteration was noticed during transportation in non-air-conditioned vehicle in both conditions (figure 29).

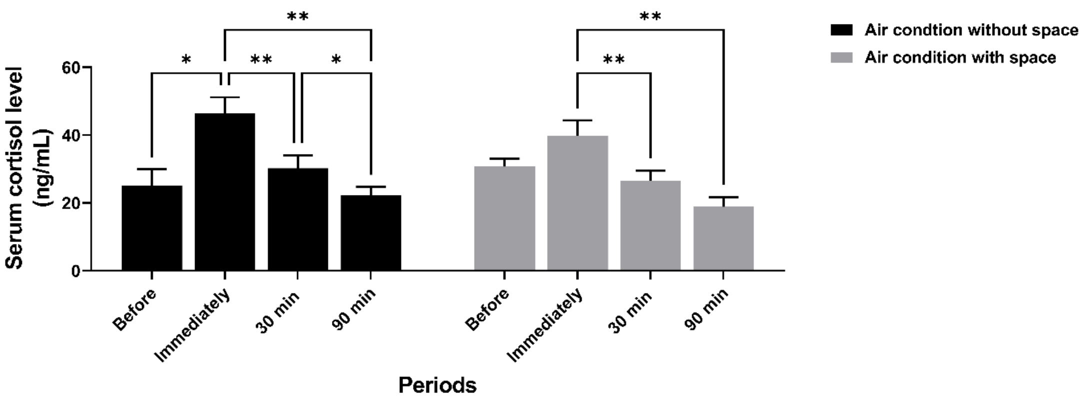


Figure 28: *Cortisol level in response to transportation air condition vehicle without spacing (left panel) and with spacing (right panel). The cortisol levels were measured at before transportation, immediately after transportation, 30 and 90 min after transportation.*

* indicate *p* < 0.05 between pairs of the comparison.

** indicate *p* < 0.01 between pairs of the comparison.

*** indicate p < 0.001 between pairs of the comparison.

**** indicate p < 0.0001 between pairs of the comparison

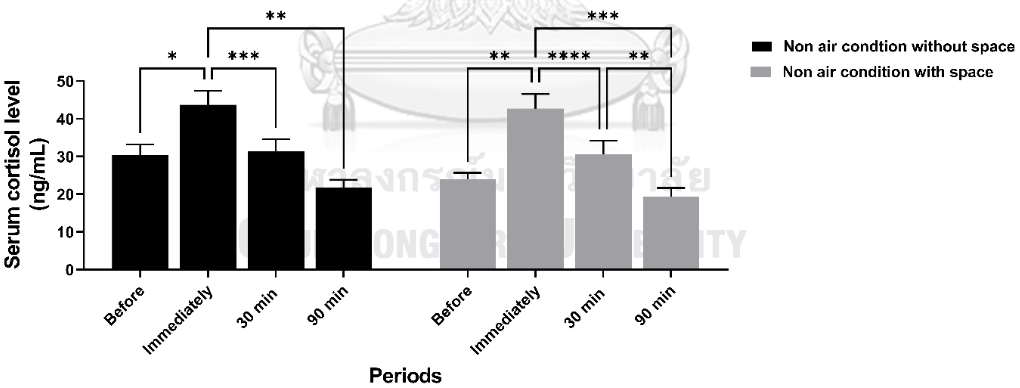


Figure 29: *Cortisol level in response to transportation non-air condition vehicle without spacing (left panel) and with spacing (right panel). The cortisol levels were measured at before transportation, immediately after transportation, 30 and 90 min after transportation.*

* indicate *p* < 0.05 between pairs of the comparison.

** indicate *p* < 0.01 between pairs of the comparison.

*** indicate p < 0.001 between pairs of the comparison.

**** indicate p < 0.0001 between pairs of the comparison

Blood cortisol level

Blood cortisol levels determined before transportation, immediately after transportation, 30 min and 90 min after transportation are demonstrated in table 11. Changes in the cortisol level in different condition are as follows;

Table 11. Blood cortisol level in response to different transportation conditions

Transportation conditions	Blood cortisol level (ng/mL)			
	Before transportation	After transportation		
		Immediately	30 min	90 min
ACT	25.17 ± 4.77	46.33 ± 4.80*	30.17 ± 3.84$^{\#\#}$	22.17 ± 2.57$^{\#\#}$
NACT	30.33 ± 2.84	43.67 ± 3.75*	31.33 ± 3.24$^{\#\#\#}$	21.17 ± 2.16$^{\#\#}$
ACTSP	30.67 ± 2.33	39.83 ± 4.47	26.50 ± 3.04$^{\#\#}$	18.83 ± 2.85$^{\#\#}$
NACTSP	24.00 ± 1.69	42.67 ± 3.91**	30.50 ± 3.70$^{\#\#\#\#}$	19.33 ± 2.33$^{\#\#\#}$
CPT	30.33 ± 3.76	47.00 ± 3.65	33.33 ± 0.33	20.67 ± 1.65$^{\#}$

ACT; Air-conditioned truck, NACT; Non-air-conditioned truck, ACTSP; Air-conditioned truck with space loading, NACTSP; Non-air-conditioned truck with space loading, CPT; Car-pulling trailer

* indicate $p < 0.05$ when compared to the value before transportation.

** indicate $p < 0.01$ when compared to the value before transportation.

$^{\#}$ indicate $p < 0.05$ when compared to the value immediately after transportation.

$^{\#\#}$ indicate $p < 0.01$ when compared to the value immediately after transportation.

$^{\#\#\#}$ indicate $p < 0.001$ when compared to the value immediately after transportation.

$^{\#\#\#\#}$ indicate $p < 0.0001$ when compared to the value immediately after transportation.

The cortisol level in horses in both air-conditioned and non-air-conditioned trucks increased immediately after transportation and reduced at 30 min and 90 min after transportation. Although there was no change in cortisol level immediately in horses after transportation in car-pulling trailer. A reduction in the cortisol level was detected later than the other transportations at 90 min.

Transportation with spacing in air-conditioned truck cause no increase in cortisol level immediately after transportation; however, a decline in cortisol level was also observed at 30 and 90 min similar to those described in horses transported in air-conditioned truck without spacing. On the contrary, spacing produce on effect on the cortisol level as the similar trend of cortisol alteration was noticed during transportation in non-air-conditioned vehicle in both conditions.

Heart Rate

Figure 30 presented a sample of horse heart rate during an hour of transportation. A closer investigation suggested that the heart rates was jumpy which suggested that horses may have experienced stressful incidents during transportation even if the cortisol level suggested of stress were found when compared among modes of transportation.

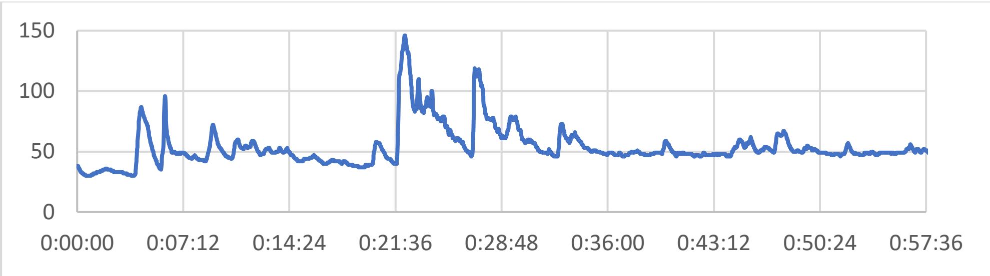


Figure 30: a sample of horse heart rate during 1 hour of transportation

The heart rate result show that there is difference in heart beats in every horse during the transportation, which shown in the graph jumping, increasing, decreasing and inconsistence. Therefore, a further investigation, opinions and consult from veterinarians who are expert on equestrian horse suggested that while cortisol level in horses show no significantly impact, for the result in different types of transportation vehicles. Therefore, heart rate differences of five beats within 1 second would consider as heart rate jump and indicated that horse felt stressful.

Discussion

In the present study, we investigated the effects different types of transportation modes on serum cortisol level and heart rate in horses. The results from this experiment were later applied for establishing the decision-making model for the most appropriate transportation protocol in horses in tropical country. As the sequential changes in serum cortisol level in horses fully loading in air-conditioned and non-air-conditioned trucks were somewhat similar. The condition of truck has no effect on the change in cortisol level. With regard to the loading conditions, the changes in cortisol level in horse with space loading were also similar in horses with full loading in non-air-conditioned truck. Interestingly, the unchanged in cortisol levels was found between pre and immediately post transportation in horses with space loading. Hence the loading condition has an effect only in the horses in the air-conditioned truck. It was indicated that the stress level was lower in horses in air-conditioned truck. The possible factor causing unchanged in the cortisol level was that, in low ventilation environment, the horses were comforted by the spacing during transportation even the temperature was not high.

Conclusion

There was no difference in stress level in horses fully loading in the air and non-air-conditioned truck. A lower in stress level was noted in the horse with space loading when compared to fully loading in the air-condition truck. This result may aid the selection of loading condition in horses during transportation with air-conditioned vehicle.

Chapter 4 : Equestrian Horse Transportation Model Development

The objective of the second stage was to develop a mathematical model to ensure horse welfare while minimize costs of transportation. While the cortisol level in horses from Stage 1 suggested modes of horse transportation had no impact on horse stress, a closer investigation of heart rates during transportation suggested otherwise. After careful investigation and opinions from veterinarians who are an expert on equestrian, it suggested that the heart rate differences of five beats within 1 second would consider as heart rate jump and indicated that horse felt stressful. Next, a problem description will be discussed.

Problem Description

We consider a transportation problem of *n* horses to transport from a stable to a competition venue. The duration of transportation is *H* hours. Each horse (i) experiences an average of J_i jumps per hour. The average jumps per hour can be found by attaching a heart rate monitor and collect data during the transportation process as described in the previous chapter. The horse transportation can be allocated to V types of vehicles. Each vehicle type (v) has a capacity of Cap_v and incurs a cost of transportation C_v. This transportation cost can be modeled by the distances or by the duration. Moreover, it can include driver wages into the cost. The objective function is to minimize the cost of transportation and prevents the number of heart rate jumps. To model the heart rate jumps, we introduced the penalty cost λ to capture the damage of the horse condition due to the heart rate jumps.

The nomenclature is as follows.

Decision variable x_i = the number of vehicle type i used

n_i = the number of horses on vehicle type i

Parameter C_i = the cost of transportation of vehicle type i

J_i = the average horse heart rate jumps per hour per horse of vehicle type i

Cap_i = The capacity of vehicle type i

λ = the penalty cost or the cost estimation per jump

H = how long horses needed to be transported (in hours)

Π = total number of horses needed to be transported

Objective function: To minimize horse transportation costs and horse heart rate jumps

$$\text{Min} \sum x_i [c_i + \lambda \text{H}\, J_i\, Cap_i]$$

The first term of the objective function describes the total cost of transportation. The transportation cost is the number of vehicles (x_i) multiplied by the transportation cost (c_i). The second term models the penalty costs due to stresses during transportation. $J_i n_i$ is the total number of jumps happened in each vehicles i per hour. Once $J_i n_i$ is multiplied by H, it gives the total number of jumps happening during the transportation. Finally, the multiplication of the penalty cost per jump (λ) to $\text{H}(J_i n_i)$ will provide the monetary penalty cost due to horse stresses during transportation.

Constraints:

1. Every horse must be transported.

$$\sum n_i = \Pi$$

2. Capacity constraint: the total number of transported horses in vehicle i cannot exceed the capacity of vehicle type *i* multiplied by the number of vehicle type i.

$$n_i \leq x_i Cap_i$$

3. Nonnegative constraint: the number of vehicle types and horses must not be negative value.

n_i and x_i ≥ 0 and integer

The mathematical model was implemented in Excel and solved using Solver Add-in. Transportation managers as well as stable owners are, therefore, able to use and implement our model to minimize the transportation cost while maximize horse welfare.

Excel Development

In order to mathematically solve the problem, Excel Solver was used.

Step 1: Activate Excel Solver. Excel Solver Solver is a Microsoft Excel add-in program that use for what-if analysis. The solver can find an optimal (maximum or minimum) value for a formula in one cell, subject to constraints, or limits, on the values of other formula cells on a worksheet.

Step 2: Open New Sheet and go to Data then solver (Figure 31)

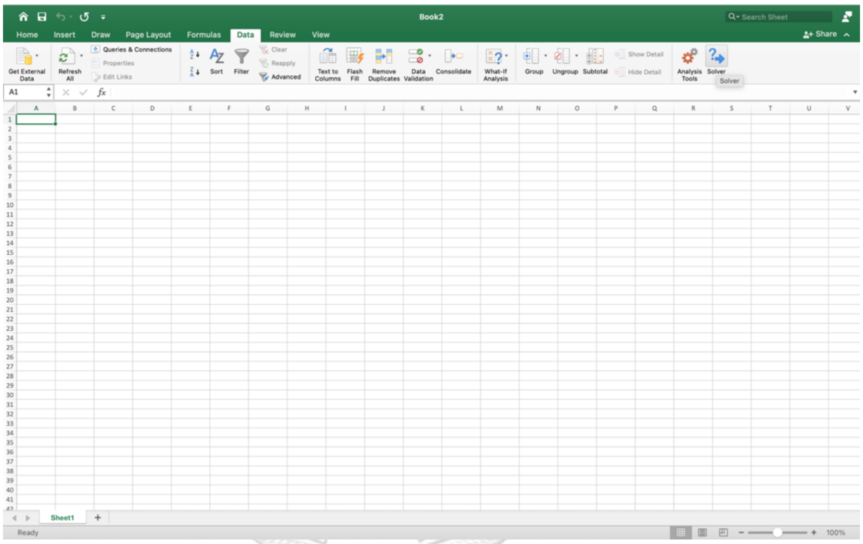


Figure 31: Open New Sheet and go to Data then solver

Step 3: Once the solver was clicked, the Solver Parameter box would appear as seen below. (Figure 32)

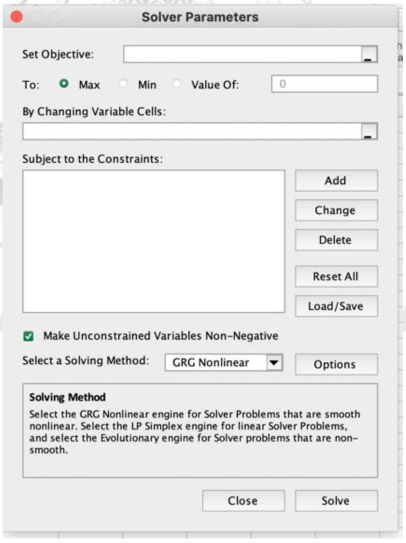


Figure 32: Once the solver was clicked, the Solver Parameter

Step 4: Set up model parameters, We began by putting key parameters which were 1. Vehicle capacity, 2. Average Number of Jump per Hour per Horse, 3. Vehicle cost, 4. Travel Duration 5. Total number of horse transported 6. Penalty cost. (Figure 33)

	A	B	C	D	E	F	G
1		capacity	avg jump /hr/horse	cost	hours	total horse	Penalty Cost
2	non air	8	5.93	28000	3	50	200
3	air condition	6	4.63	24000			
4	non air	6	5.83	24000			
5	air condition	3	4.43	24000			
6	non air	3	4.73	24000			
7	non air	3	5.5	15000			
8	non air trailer	2	7.25	7500			
9	non air trailer	1	2	7500			

Figure 33: Set up model parameters

Step 5: Set up decision variables. We set up decision variables in cells H1-H9 and I1-I9, Cells H indicated the number of vehicle type I (x_i), while cells I indicated the number of horses transported in vehicle type i (n_i). In the solver parameter box, we input Sheet1!$H$2:$I$9 (Figure 34)

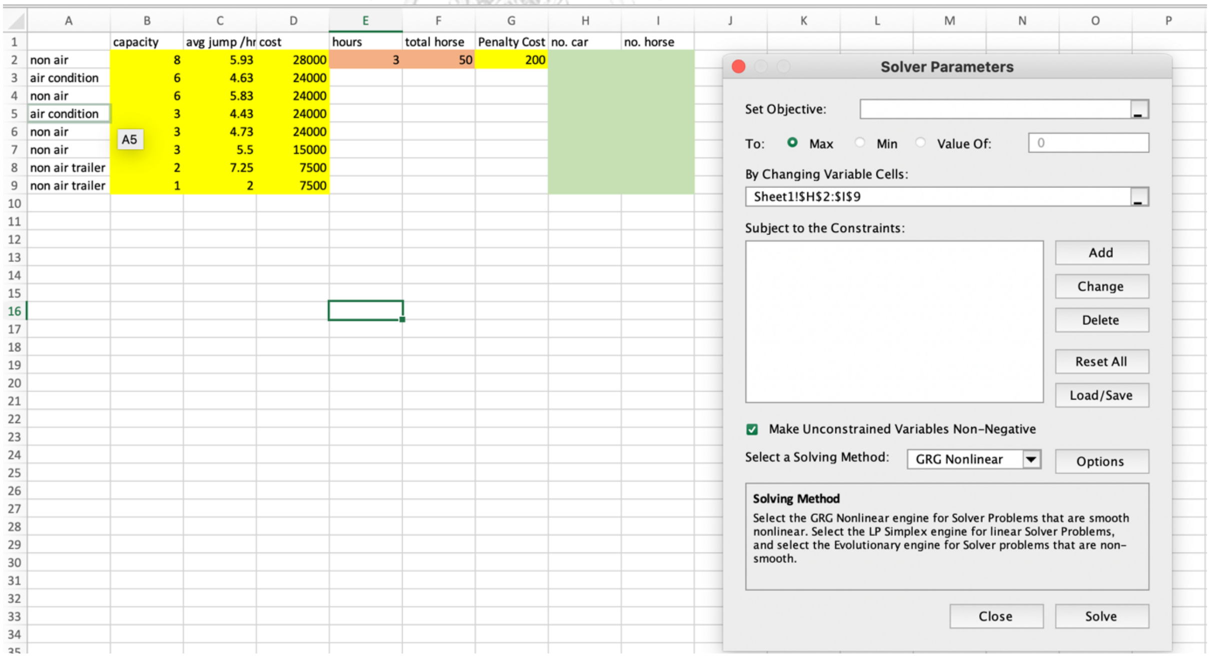


Figure 34: Set up decision variables

Step: 6 Set up Objective function. The objective function was calculated by $\mathrm{Min}\sum x_i[c_i + \lambda \mathrm{H}\, J_i\, Cap_i]$ objective function

For simplicity, we built the objective function into two terms. The first term indicated the costs of transportation which were modeled in CellsD14:D21 which calculated as the decision variables (x_i) in CellsH2:H9 multiplied by its costs in CellsD2:D9. (Figure 35)

	A	B	C	D	E	F	G	H	I
1		capacity	avg jump /hr	cost	hours	total horse	Penalty Cost	no. car	no. horse
2	non air	8	5.93	28000	3	50	200		
3	air condition	6	4.63	24000					
4	non air	6	5.83	24000					
5	air condition	3	4.43	24000					
6	non air	3	4.73	24000					
7	non air	3	5.5	15000					
8	non air trailer	2	7.25	7500					
9	non air trailer	1	2	7500					
10									
11	objective	cost	0	0					
12		health	0						
13	constraint	total horse	0						
14	non air	num car	0	=H2*D2	0				
15	air condition		0	0	0				
16	non air		0	0	0				
17	air condition		0	0	0				
18	non air		0	0	0				
19	non air		0	0	0				
20	non air trailer		0	0	0				
21	non air trailer		0	0	0				
22			num car*car	car cost	horse health				

Figure 35: Set up Objective function

The penalty cost was modeled as the average jump per horse happened in vehicle i multiplied by the number of horses transported in vehicle type i (Figure 35). The penalty cost was modeled by multiplying the duration of transportation, the penalty costs, and the total number of jumps. (Figure 36)

	A	B	C	D	E	F	G	H	I
1		capacity	avg jump /hr	cost	hours	total horse	Penalty Cost	no. car	no. horse
2	non air	8	5.93	28000	3	50	200		
3	air condition	6	4.63	24000					
4	non air	6	5.83	24000					
5	air condition	3	4.43	24000					
6	non air	3	4.73	24000					
7	non air	3	5.5	15000					
8	non air trailer	2	7.25	7500					
9	non air trailer	1	2	7500					
10									
11	objective	cost	0	0					
12		health	0						
13	constraint	total horse	0						
14	non air	num car	0	0	=C2*I2				
15	air condition		0	0	0				
16	non air		0	0	0				
17	air condition		0	0	0				
18	non air		0	0	0				
19	non air		0	0	0				
20	non air trailer		0	0	0				
21	non air trailer		0	0	0				
22			num car*car	car cost	horse health				

Figure 36: The penalty cost was modeled as the average jump per horse happened in vehicle i multiplied by the number of horses transported in vehicle type i

	A	B	C	D	E	F	G	H	I
1		capacity	avg jump /hr	cost	hours	total horse	Penalty Cost	no. car	no. horse
2	non air	8	5.93	28000	3	50	200		
3	air condition	6	4.63	24000					
4	non air	6	5.83	24000					
5	air condition	3	4.43	24000					
6	non air	3	4.73	24000					
7	non air	3	5.5	15000					
8	non air trailer	2	7.25	7500					
9	non air trailer	1	2	7500					
10									
11	objective	cost	0	0					
12		health	=E2*G2*SUM(E14:E21)						
13	constraint	total horse	0						
14	non air	num car	0	0	0				
15	air condition		0	0	0				
16	non air		0	0	0				
17	air condition		0	0	0				
18	non air		0	0	0				
19	non air		0	0	0				
20	non air trailer		0	0	0				
21	non air trailer		0	0	0				
22			num car*car	car cost	horse health				

Figure 37: The penalty cost was modeled by multiplying the duration of transportation, the penalty costs, and the total number of jumps

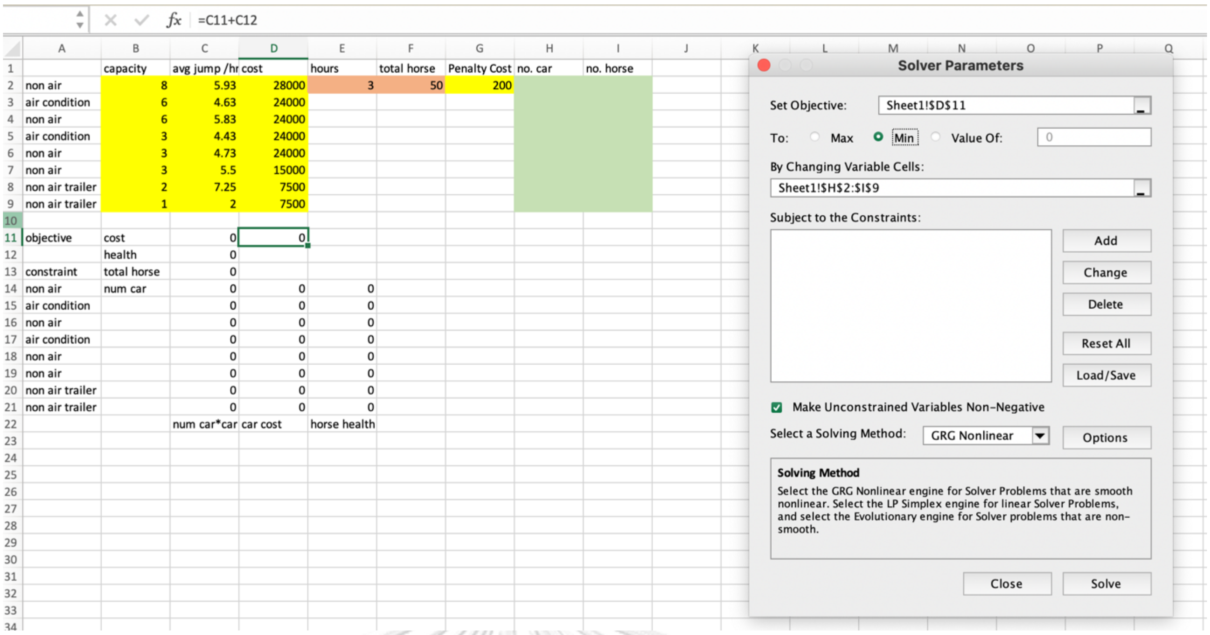
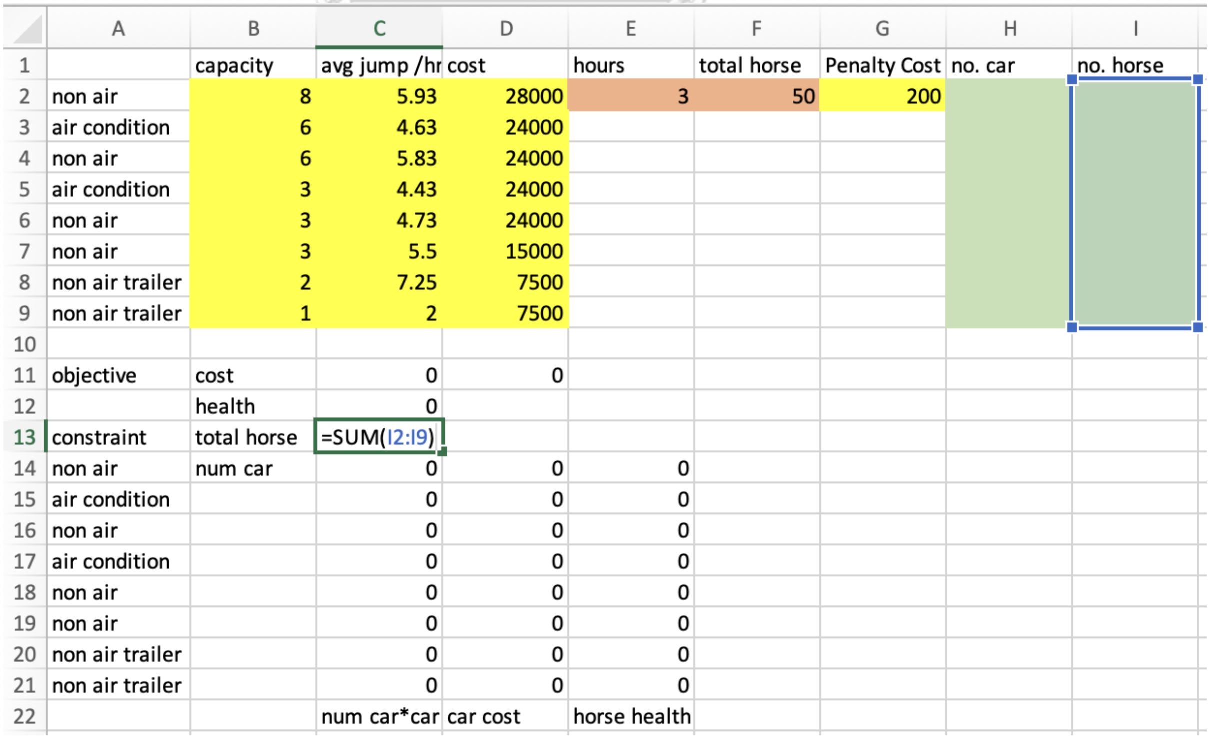


Figure 38: The objective function was put in Set objective and we selected D11 which were the summation of the costs of transportation and the penalty cost. And select min in the solver parameter block

Step 7: Set up Total Horse Constraint where every horse must be transported $\sum n_i = \Pi$

First, we began by setting up Cell C13 as the summation of cells I2:I9 (Figure 39)



	A	B	C	D	E	F	G	H	I
1		capacity	avg jump /hr	cost	hours	total horse	Penalty Cost	no. car	no. horse
2	non air	8	5.93	28000	3	50	200		
3	air condition	6	4.63	24000					
4	non air	6	5.83	24000					
5	air condition	3	4.43	24000					
6	non air	3	4.73	24000					
7	non air	3	5.5	15000					
8	non air trailer	2	7.25	7500					
9	non air trailer	1	2	7500					
10									
11	objective	cost	0	0					
12		health	0						
13	constraint	total horse	=SUM(I2:I9)						
14	non air	num car	0	0	0				
15	air condition		0	0	0				
16	non air		0	0	0				
17	air condition		0	0	0				
18	non air		0	0	0				
19	non air		0	0	0				
20	non air trailer		0	0	0				
21	non air trailer		0	0	0				
22			num car*car	car cost	horse health				

Figure 39: Set up Total Horse Constraint

Next we set up the horse transportation constraint in the solver parameter box by adding constraint

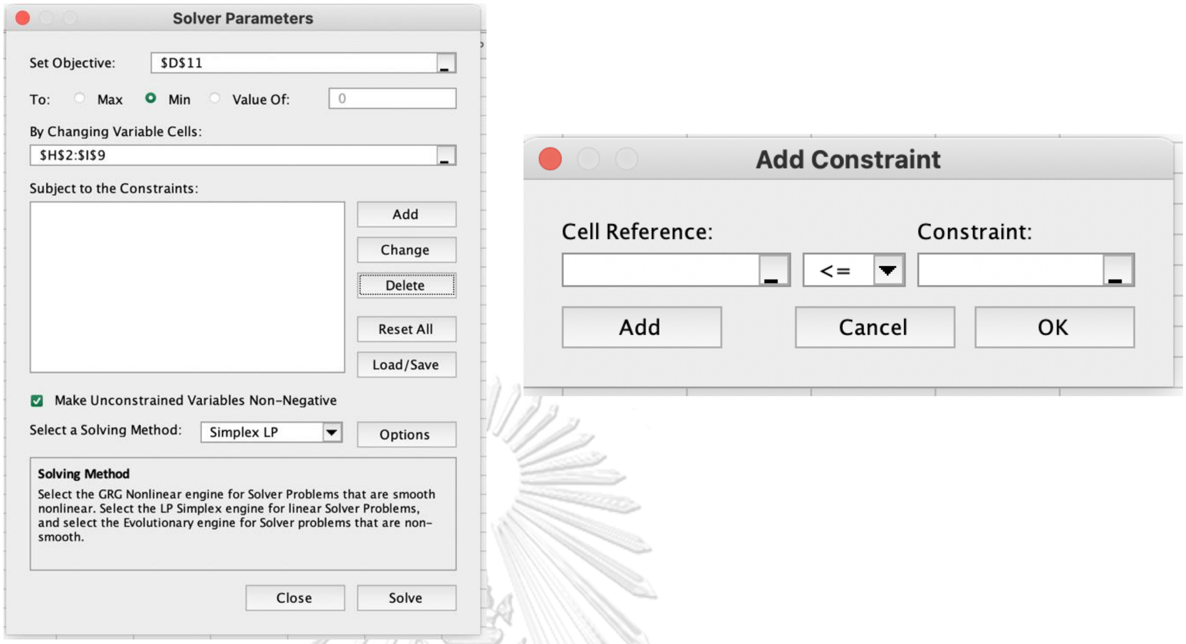


Figure 40: set up the horse transportation constraint

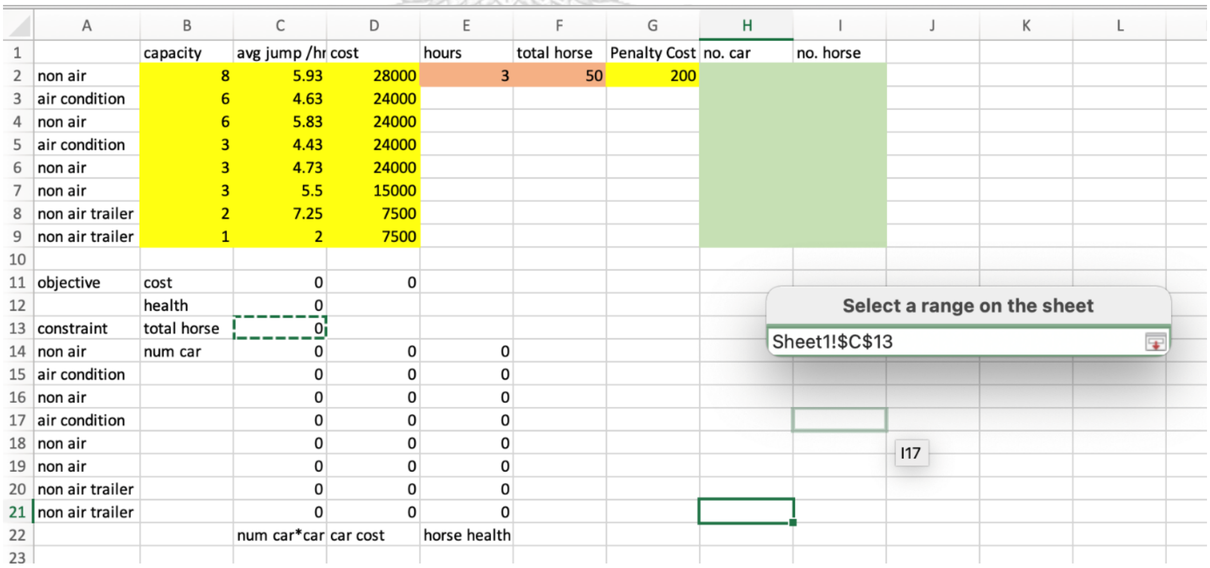


Figure 41: Cell C13 indicated the total number of horse transported and the right hand side was set to equal the total horses in the parameter set up.

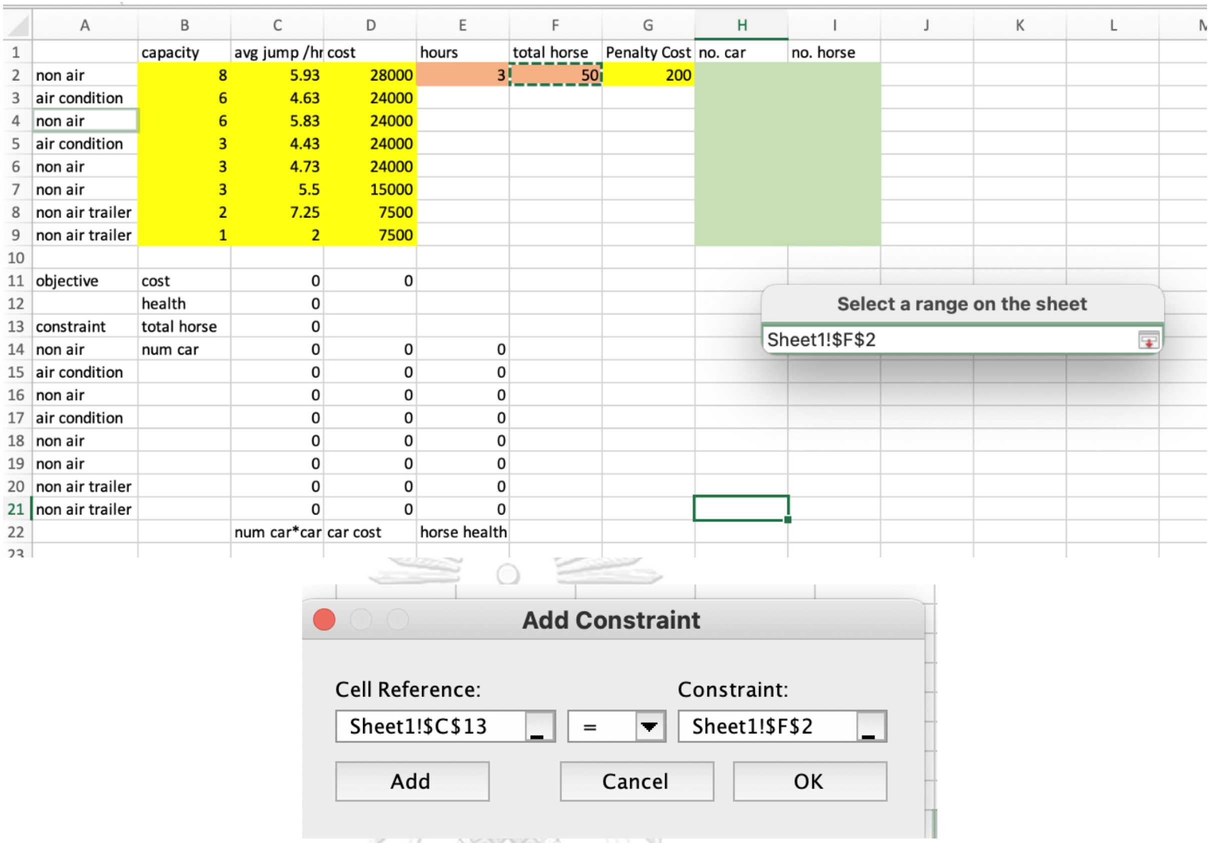


Figure 42: set left hand side cell reference and right hand side constraint

Once we set the left hand side and right hand set click add, and we got.

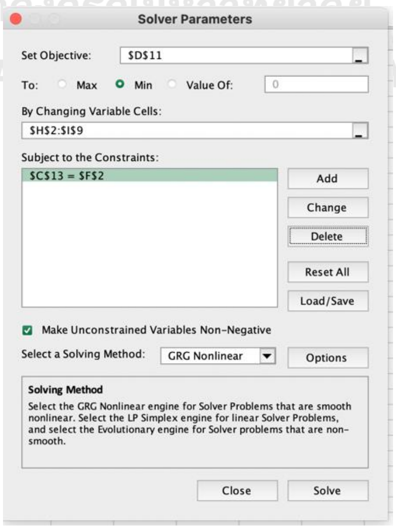


Figure 43: Solver parameters set "Subject to the constraints"

Step 8: set up capacity constraint

SUM =H2*B2

	A	B	C	D	E	F	G	H	I
1		capacity	avg jump /hr	cost	hours	total horse	Penalty Cost	no. car	no. horse
2	non air	8	5.93	28000	3	50	200		
3	air condition	6	4.63	24000					
4	non air	6	5.83	24000					
5	air condition	3	4.43	24000					
6	non air	3	4.73	24000					
7	non air	3	5.5	15000					
8	non air trailer	2	7.25	7500					
9	non air trailer	1	2	7500					
10									
11	objective	cost	0	0					
12		health	0						
13	constraint	total horse	0						
14	non air	num car	=H2*B2	0	0				
15	air condition		0	0	0				
16	non air		0	0	0				
17	air condition		0	0	0				
18	non air		0	0	0				
19	non air		0	0	0				
20	non air trailer		0	0	0				
21	non air trailer		0	0	0				
22			num car*car	car cost	horse health				

Figure 44: set up capacity constraint

First, we set up a cell to indicate the number of vehicle type I multiplied by the capacity in order to set a capacity limit for the total number of horses transported in vehicle i. (Figure 44) After that we set up the parameter box as follows (Figure 45)

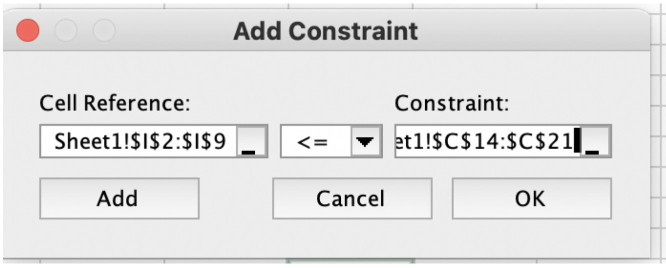


Figure 45: Add constraint

After we set up the parameter box as follows (Figure 45), Then will get; (Figure 46)

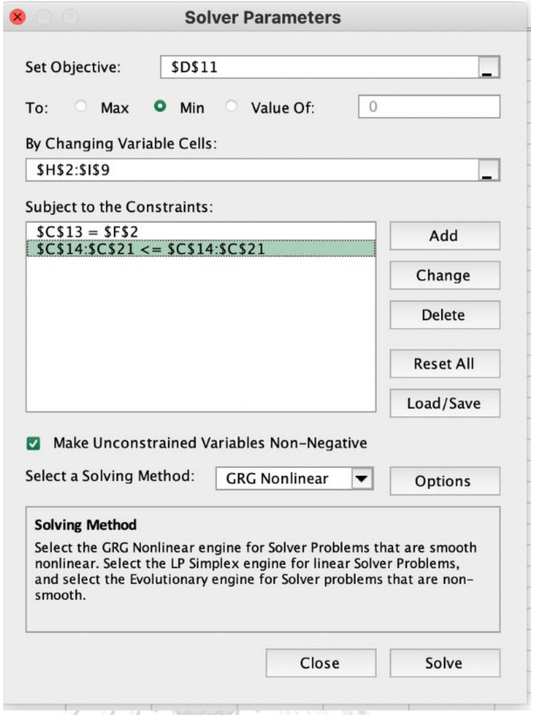


Figure 46: Solver parameters set "Subject to the constraints"

Step 8: set up integer and nonnegative constraint

We select every decision variable and set it in the parameter box by using int which indicates that decision variable will only take integer values, and select >= 0 by setting zero as the right hand side.

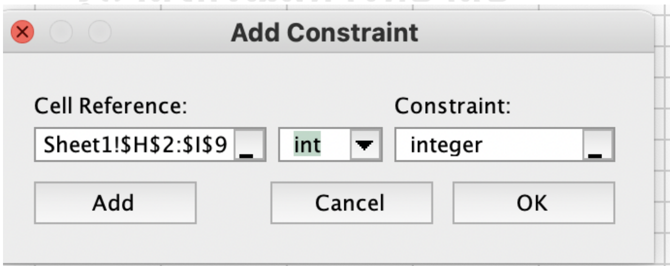


Figure 47: set up integer

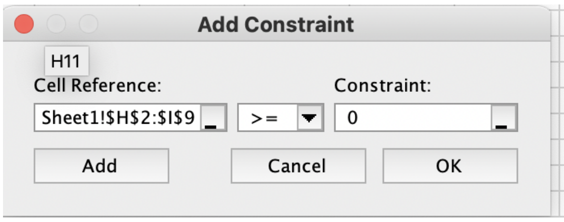


Figure 48: nonnegative constraint, select >= 0 by setting zero as the right hand side

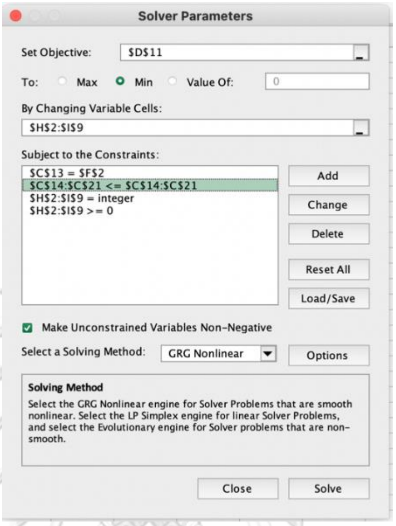


Figure 49: Solver parameters set "Subject to the constraints"

Step 9: solve the problem

Select a solving method. For simplicity, we select Simplex LP

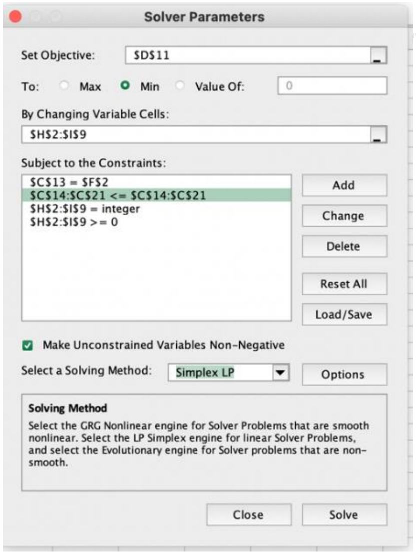


Figure 50: solve the problem, select Simplex LP

After all the step, then we Solve

	A	B	C	D	E	F	G	H	I
1		capacity	avg jump /hr/horse	cost	hours	total horse	Penalty Cost	no. car	no. horse
2	non air	8	5.93	28000	3	50	200	1	8
3	air condition	6	4.63	24000				7	42
4	non air	6	5.83	24000				0	0
5	air condition	3	4.43	24000				0	0
6	non air	3	4.73	24000				0	0
7	non air	3	5.5	15000				0	0
8	non air trailer	2	7.25	7500				0	0
9	non air trailer	1	2	7500				0	0
10									
11	objective	cost	196000	341140					
12		health	145140						
13	constraint	total horse	50						
14	non air	num car	8	28000	47.44				
15	air condition		42	168000	194.46				
16	non air		0	0	0				
17	air condition		0	0	0				
18	non air		0	0	0				
19	non air		0	0	0				
20	non air trailer		0	0	0				
21	non air trailer		0	0	0				
22			num car*car capa	car cost	horse health				

Figure 51: finishing model to interpret result

How to interpret result

1. Objective function at cell D11 the objective function was 341140, the costs of transportation equal to 196000 and the health cost equal to 145140
2. No car used we use non air 8 capacity 1 car, and 7 cars for 6 capacity air condition
3. 8 horses transported in 8 capacity and 42 horses will transported into 7 cars of 6 air capacity

Example Problem

To illustrate our model, the following parameters obtained from real costs were input and solved.

23 horses needed to be transported for 3 hours. The parameters and results were shown in Table 12. Note that all the parameters used for the transportation cost were actual cost, while the average heart rate jump per hour per horse was calibrated from the data in the previous chapter. For the purpose of the illustrated problem, a stable owner provided two estimated value of penalty cost, which were 100 for the best-case scenario and 400 for the worst-case scenario.

Table 12: The parameter and results from the actual case.

Parameter				Result 1		Result 2	
Vehicle Type	Capacity (Cap_i)	avg jump per hour per horse (J_i)	cost (c_i)	no. car (x_i)	no. horse (n_i)	no. car (x_i)	no. horse (n_i)
non air	8	6	28000	2	16	0	0
ACT	6	4.63	24000	1	6	3	18
NACT	6	5.83	24000	0	0	0	0
ACTSP	3	4.43	15000	0	0	0	0
NACTSP	3	4.73	15000	0	0	0	0
CPT2	2	7.25	7500	0	0	0	0
CPT1	1	2	7500	1	1	5	0

The results showed that the total cost would be 125,234 THB where the actual transportation costs would be 87,500 THB, while the penalty costs of poor welfare was 37,734 THB equivalent. Overall, the horses would experience 130 stressful incidents during the course of transportation. The horses were transported in 2 non-air conditioning trucks of eight horses, and 1 air conditioning of 6 horses, and one horse in a trailer.

However, if the penalty cost was estimated to be 400. The results would have changed to Result 2 in Table 12 where it was better to transport 18 horses in 3 air conditioning truck of 6, and 5 trailers for one horse each. This was because the penalty costs were relatively high when compared to transportation costs.

Technology Acceptance Model Analysis

The testing of transporting model with the targeting horse's responsible people to transport horses in Thailand, was tested with an in-depth interview. Where these horse's responsible people tested the decision-making model and give their opinion about the model

Population and sample used in research

The inclusion criteria for the people for this in-depth interview is criteria by the minimum number of horses they own and the minimum number of competitions they took part in. Theses group of interview people can be horse owners, stable owners, equestrian athlete, equestrian coaches. The requirement of inclusion are as follow;

- Horse owners, stable owners, equestrian athlete, equestrian coaches who own a minimum number of 10 horses
- Horse owners, stable owners, equestrian athlete, equestrian coaches who have experience in equestrian competition at least 5 years

- Horse owners, stable owners, equestrian athlete, equestrian coaches who are 18 years old or older

Questions for the in-depth interview

- Is the model easy to use?
- Is the model work, do you have any opinion about the model?
- Is the model effective, and correct?
- Do you think the model will help you to sort the transportation in the future?
- Please score the model from 1 (very bad) 2 (bad) 3 (normal) 4 (good) 5 (very good)

Model Limitation

While the proposed model can be easily solved and accepted by several stable owners, it has some limitations. The model relies on the estimation and interpretation of horses' condition. This thesis proposed to capture the horses' condition from its heartrates. However, there can be other inputs to be used as a proxy of the horses' conditions, or it can also be a multivariable function rather than a single function in our case. For example, a multivariable function of heartrates, cortisol level, and temperature, may be able to better capture horses' condition. The increases of input variables increase computational difficulties and may not worth the effort. In our case, the veterinary experts confirmed that the use of heartrates was sufficed to indicate the horses' condition.

The second limitation is the penalty cost estimation. The penalty cost estimation depends on many factors. The penalty cost can also be estimated from the winning expectation of the horse owner. If the horse owner expects to win the race, they should prepare their horse to have the best condition. During transportation, the horses should expect smooth and pleasant journey which may come with high transportation cost. Failure to execute smooth journey results in poor condition and may affect the race. As a result, higher penalty cost should incur in order to capture the winning expectation of owners.

The third limitation is the distance travel in this experiment which is set at 250 kilometers with approximately 5 hours. It could be effect by the traffic on the day of experiment which cannot be control on the duration of travel. With the unpredictable of traffic on the day of each experiment vehicle type, but it is based on real situation horse transportation to competitions. The other factors of limitation is the external factor of environment which is different every day, but this is another factors that can happen in real situation of horse transportation.

Finally, the thesis was derailed from the pandemic of COVID-19 and African Horse Sickness (AHS) outbreak in Thailand. The arrival of the pandemic resulted in cancellation of equestrian competitions. The horses, therefore, never had any transportation experiences during last three years. As a result, it was also possible that the horses may feel uneasy during the transportation and it reflected on the heartrate jump parameters in the model.

Model Extension

Several extensions can be made to the current model in order to better capture the specific needs of owners. While this model was proposed as an integer model, the model did not address the horses as an individual. The model treated horses as an aggregate entity. However, different horses have different characters. The model can be extended to address the character of a horse and treated it as an individual entity. To extend the model to treat horses as an individual entity, the transportation problem will probably need to change to an assignment problem where we assign which horse is to transport by which type of car. This future extension while is not difficult to implement, it requires a lot more computation to the proposed model.

Conclusion

In this chapter, we proposed an equestrian horse transportation model to balance between the transportation costs and horses' condition. The mathematical model was developed as an integer program whose decision variables included the amount of horses to transport in each type of vehicles and the number of each type of vehicle to be used in the transportation. The objective function was to minimize the transportation costs and penalty costs due to stresses. The stresses or condition was modeled from the heartrate. The parameter of the model, such as, transportation costs and car capacity, were collected from stable owner. The model was implemented using Excel Solver. Technological Acceptance Model was employed and we found positive feedbacks by stable owners suggesting that the model was easily implemented and beneficial for uses in the real-world application of equestrian horse transportation.

Chapter 5: Benefits of Equestrian Horse Transportation to Sports Management

Sports management is the major key business parts for a sport event to be successful and it is an overview to the sport competition events. It involves many combinations of skills that combine the skills of planning, organizing, directing, controlling, leading, budgeting and any other relative area. As sport management guide the sport event to run as smooth as possible it involves back to the start till the end of the event. Different people are responsible in different area as they have the job to be responsible to make the event happen. As the perspective of sports side of view, sport management start since the pre-competition to post-competition. Now a day application and technology come in the sport world and help to move the sport forward. It makes it easier for people to make the decision with less human errors in different situations.

Sport management of equestrian start back home at each individual home based stable. As horses is a sensitive, with unique behavior. It is clear for all athlete to prepare the horses health's condition to be ready as much as possible for a coming up competitions. The most important for equestrian sport is the horse welfare which all athlete are control under the FEI FEI (Fédération Equestre Internationale) Horse Welfare rules and protocols. The pre-competition for equestrian starting at home stable with preparing horses, training horses, checking health status, facility cleaning, facility control for training. After all the preparation at home stable, when it's come to competition. The first major important part to move the horses to the located competitions area is how the horses will be transport. It is one of the most important part due to those horses will be located and loaded onto an unnatural environment which is the horse truck or horse trailer, which there is a high risk of injury if the trip is not plan carefully. Therefore, athlete need to plan and take good care to keep the horses' health condition as best as possible. After the horses been move to competition locations, other factors of management will follow with stable management, to prepare bedding, food and clean water. During competition athlete will have a set of riding plan to warm-up the horses and then competition. After all the competition, since horse welfare is the number one priority, athlete and responsible people take care of the horses by checking the horse's health status before transporting horses back to the home stable. After all the competition there always a risk of injury due to the high-density work. Therefore, the way to transport horses back is also the part that can not be forgotten.

As the sport of equestrian has grown through the years in Thailand with more horses been transported to different places for different activities and purposes. As owners and relative responsible people do not have the knowledge on the effects that transportation can have an impact on the health of the horses. It is one of the main parts of sport management to transport horses in the equestrian sport, as the competition venue is located all over Thailand. Owners or relative responsible have been overlook and pay less attention to this management part due to that there might not be a method or guideline to educate them.

This paper introduced a mathematical model for equestrian horse transportation. The study was divided into two stages. The first stage compared the stress level of transported horses using cortisol as well as heart rate, while the second stage developed a mathematical model that balanced between horse health and transportation cost.

For the first stage of the study, investigate the transportation of horses in different vehicles to test what can impact the horse's health status during different type of transportation and also with different capacity that been transported. There were 3 types of different transportation vehicles used in the experiment which are Horse Air-Conditioning Truck, Horse Non-Air-Conditioning Truck and Horse Trailer. The experiment of transporting horses in different transportation vehicles and the capacity of horses give us information and result to find the best transporting method for the health of the horses. With the result of different vehicle types, there are also different other measurement that involve to find the balance between the cost and the health of the horses. The cost and benefit health status analysis give us a clearly vision to create a mathematical model to management the transportation of horses and a reasonable cost. The results suggested that different mode of transportation resulted in different stressfulness in horses. Though there were no statistical differences found when compared among different modes of transportation, the stress levels collected immediately after transportation were statistically significant compared to pre transportation in several modes of transportation. The results also showed that horses transported in air conditioning truck with space or in trailer (only 2 horses allowed) had no statistical different of cortisol levels between pre transportation and immediately after transportation. The results suggested that transporting horses with spacing would be more appropriate.

While cortisol level was a good measure of stressfulness, it was a collective information during transportation. In our study, heart rates were collected and presented many spiky patterns which may indicate stressful incidents happened to horses. Our results (Table 12: *The parameter and results from the actual case*) showed that a jump in heart rate was higher when horses travelled in non-air conditioning than in air conditioning trucks. Moreover, horse welfare was better when they were transported in small number rather than in large number. It should also be noted that the heart rate jump was highest when two horses travelled in trailer due to very tight space of the trailer.

The second stage of the study was to develop a mathematical model used to find a mode of transportation that balance between costs and horse welfare. The model was implemented in Excel and solved using its Solver Add-in. The proposed model was a simple yet powerful where the penalty cost was implemented to capture horse welfare. As a result, the model balanced between lowest costs of transportation while preserving horse welfare. Modelers, therefore, need to carefully calibrate the penalty cost. The model can be easily extended by modelers. For example, the modeler can model penalty cost function for each horse to indicate the importance of some horses that may need special care. The model can also be modeled to take into account of environments by adding another penalty cost for environment. While the presented model was a deterministic model, a stochastic model similar to the one proposed by Gupta and Lawsirirat (2016) can also be implemented where horse heart rate can be modelled using a continuous time jump diffusion model. The model will help mimic patterns of horse heart rate and provide useful insight information during transportation.

While our study was the first attempt to study equestrian horse welfare during transportation and develop a mathematical model to select the most appropriate mode of transportation, it was without limitations. First, our scope of study limited the duration of transportation to no greater than 5 hours. Our results may not be extended to longer hours of transportation. Moreover, same horses were transported to the same route over the courses of three weeks. This might influence stress level in horses. Lastly, our mode of transportation was limited to trucks and trailers. However, the model can be easily extended to other types of transportations, but the parameters needed to be re-calibrated.

The mathematical model was developed by using the information and results from the experiment to find the balanced between horse health and transportation cost which can helps the athlete in the future to manage the transportation of horses. The model proved and ensure that the horses will be transported in a suitable way and owners can afford the cost to maintain the best horse's health status. In the sport of equestrian transportation is one of the biggest managements occur due to that it is the movement of living animal which in every movement is a risk, and all the aspect that we can minimize the risk is beneficial to the performance of athlete and horses in the competition field. With the model we create, it benefits and give owner clear and easy way to manage the transportation and save owner's time to think about the transportations type which will be best for the horses, or to help owner to make the best decision with a reliable source of information to make decision with decreasing human errors. The benefit of the model helps the horse owners to select the most appropriate mode of transportation which helps maximize chances of winning.

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ADPPENDICES

APPENDIX A

EQUESTRIAN HORES TRANSPORTATION

VITA

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