Original Article

CREATING OPTIMAL EQUESTRIAN TRANSPORTATION STRATEGY BY BALANCING BETWEEN HORSE WELFARES AND COSTS

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Abstract

Purpose This paper developed a mathematical model to select the most appropriate mode of equestrian horse transportation which balanced between costs of transportation and horse welfare.

Methods 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. Six horses were recruited into this study. They were transported by different types of vehicles, i.e., air conditioning/non air conditioning and with/without space trucks and a trailer with/without space. The horses were transported for 5 hours with about 250 kilometers. Horses were transported once a week for three weeks. The cortisol level and heart rate were collected.

Results The results showed that different mode of transportation resulted in different stressfulness in horses. A mathematical model was constructed to minimize transportation costs as well as penalty costs of poor horse welfare. The decision variables included the type of transportation vehicle and the number of horses transported into the transportation vehicle.

Conclusion The model was easily implemented and well received by horse owners to select the most appropriate mode of transportation for their horses.

Keywords: Horse Transportation / Vehicle Selection / Mathematical Model / Horse Welfare / Equestrian Management

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บทความวิจัย

การหาวิธีการขนส่งม้าแข่งที่เหมาะสมที่สุดระหว่างสวัสดิภาพของม้าแข่งและค่าใช้จ่ายในการขนส่ง

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บทคัดย่อ

วัตถุประสงค์ บทความเรื่องนี้ได้พัฒนาสมการทางคณิตศาสตร์เพื่อหาวิธีการขนส่งม้าที่เหมาะสมที่สุดเพื่อสร้างดุลยภาพระหว่างสวัสดิภาพของม้าแข่งและค่าใช้จ่ายในการขนส่ง

วิธีดำเนินการวิจัย การศึกษาครั้งนี้มีสองการศึกษาย่อย โดยการศึกษาย่อยที่ 1 เป็นการศึกษาหาความเครียดของม้าแข่งระหว่างการขนส่งด้วยข้อมูลฮอร์โมนคอร์ติซอล (Cortisol) และอัตราการเต้นของหัวใจ ในขณะที่การศึกษาย่อยที่ 2 เป็นการสร้างสมการคณิตศาสตร์เพื่อหารูปแบบการขนส่งม้าแข่งที่เหมาะสมเพื่อสร้างสมดุลระหว่างสวัสดิภาพของม้าที่วัดจากความเครียดจากการแข่งขัน และค่าใช้จ่ายในการขนส่ง มีการเก็บข้อมูลจากม้าแข่งจำนวน 6 ตัว โดยม้าแข่งทั้ง 6 ตัว จะถูกทำการเคลื่อนย้ายไปด้วยรถขนส่งที่แตกต่างกัน ได้แก่ รถขนส่งแบบที่มีเครื่องปรับอากาศ หรือแบบที่ไม่มีเครื่องปรับอากาศ แบบที่มีพื้นที่ระหว่างม้าแข่งหรือแบบที่ไม่มีพื้นที่ว่างระหว่างม้าแข่ง และแบบรถเทรลเลอร์แบบที่มีพื้นที่ว่างระหว่างม้าแข่ง หรือแบบที่ไม่มีพื้นที่ว่างระหว่างม้าแข่ง โดยที่ในการขนส่งนั้น ม้าแข่งจะอยู่บนรถขนส่งเป็นระยะเวลาประมาณ 5 ชั่วโมง หรือเป็นระยะทางประมาณ 250 กิโลเมตร ในการทำการขนส่งม้านั้นจะทำการขนส่งหนึ่งครั้งต่อสัปดาห์ จำนวน 3 สัปดาห์ ระดับฮอร์โมนคอร์ติซอลและอัตราการเต้นของหัวใจจะมีการวัดก่อนและหลังจากการขนส่ง

ผลการวิจัย รูปแบบการขนส่งม้าที่แตกต่างกันทำให้ม้าแข่งเกิดความเครียดที่แตกต่างกัน จากการที่มีระดับฮอร์โมนคอร์ติซอลที่แตกต่างกัน หลังจากนั้นผู้วิจัยได้สร้างโมเดลทางคณิตศาสตร์ในรูปแบบกำหนดการเชิงเส้น (Linear Programming) โดยมีฟังก์ชั่นวัตถุประสงค์ (Objective Function) เพื่อการหาค่าใช้จ่ายในการขนส่งที่ต่ำที่สุด และลดความเครียดของม้าแข่งผ่านการโมเดลความเครียดในรูปของต้นทุนค่าปรับ (Penalty Cost) ในขณะที่ตัวแปรตัดสินใจ (Decision Variables) คือ ชนิดของรถที่ใช้ในการขนส่ง และจำนวนของม้าแข่งที่ต้องการขนส่ง

สรุปผลการวิจัย หลังจากที่ผู้วิจัยได้พัฒนาโมเดลการขนส่งแล้ว ผู้วิจัยได้นำโมเดลการขนส่งที่พัฒนาขึ้นไปสอบถามกับเจ้าของม้าแข่ง พบว่า โมเดลการขนส่งม้าที่พัฒนาขึ้นมีความง่ายต่อการใช้ง่ายและสามารถใช้งานได้จริง

คำสำคัญ: การขนส่งม้า / การเลือกรูปแบบการขนส่ง / โมเดลคณิตศาสตร์ / สวัสดิภาพของม้า / การจัดการม้าแข่ง

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Introduction

Horse transportation is a critical pre-competition management for equestrian. (Leadon, Waran, Herholz, & Klay, 2008). According to the pre-competition management, horses need to be transported in a suitable method so that the risks of accident are reduced and the effects on the horse exercise performances are as little as possible (Friend, 2001). Mode of horse transportation, thus, needs to be carefully selected in order to protect horse's mood, welfare, and health condition (Wipper, 2000). Nowadays, the most frequent type of horse transportation is road transportation using horse-trailers and horse trucks. Horse trailers and trucks are specially designed to comfort the horses to minimize the horses' stress and to reduce the risk of injuries during the trip and for horses need to maintain their top condition to successfully perform at their best and many factors affect the maintenance of horse's condition in training, pre-competition, during competition and post-competition (Waran et al., 2007).

During the transportation journey, the potential stressors for horses derived from combinations of physical factors, psychological stressors, climate factors, and the horse's health status. Firstly, the physical factors include distance travel, duration, space, noise, and road condition. Secondly, psychological stressors consist of social regrouping or an unfamiliar environment. Thirdly, the climatic factors involved air temperature and relative humidity. Finally, all of these factors lead to the risk of horse health problems during transportation (Stull & Rodiek, 2000). This does not happen to every horse that traveled or happens to the same horse on a different journey, it also depends on each experience and different factors that cause the effects (Art & Lekeux, 2005).

Due to many high risks in horse transportation, it is very important to manage the transport carefully to maintain the horse's welfare and top performance. It is worth noting that unpredictable problems may occur in horses during usual transportation. The most suitable procedure for horse transportation should be primarily taken into account to preserve horse welfare. However, there was a scarcity of report 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, the present study aims to develop a decision-making model which find an appropriate method for horse transportation for Thailand. The decision-making was considered based on the study's results on the changes in biological parameters in response to different types of transportation together with the transportation expense. This information was simultaneously evaluated to develop the horse transportation model for horse owners in Thailand that minimizes transportation costs while maximizing horse welfare.

Material & methods

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. Body temperature was assessed using Digital thermometer SU-MED-013, Successpromo, China, while gut sound and respiratory rate were assessed using Stethoscope Sr2211,3m Littmann Classic II S.E., Stethoscope, China. Heart rate was determined in real-time starting from 10 minutes before the transportation and lasting till 90 minutes after the end of transportation using Polar HR monitor (H10) connected to polar sports watch (Vantage 2, Polar Electro, Oy, Kempele, Finland). 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. Serum samples for cortisol determination was assessed using a competitive chemiluminescent enzyme immunoassay (IMMULITE Analyzers; Siemens Healthineers, Erlangen, Germany). Horse behavior was observed for 90 minutes after transportation using a certified veterinarian. 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 showed 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 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. All horses were given permission by the owners to participate in the study. Moreover, ethical approval for this study was granted by the institutional board, and the horse owner provided consent form before the study began.

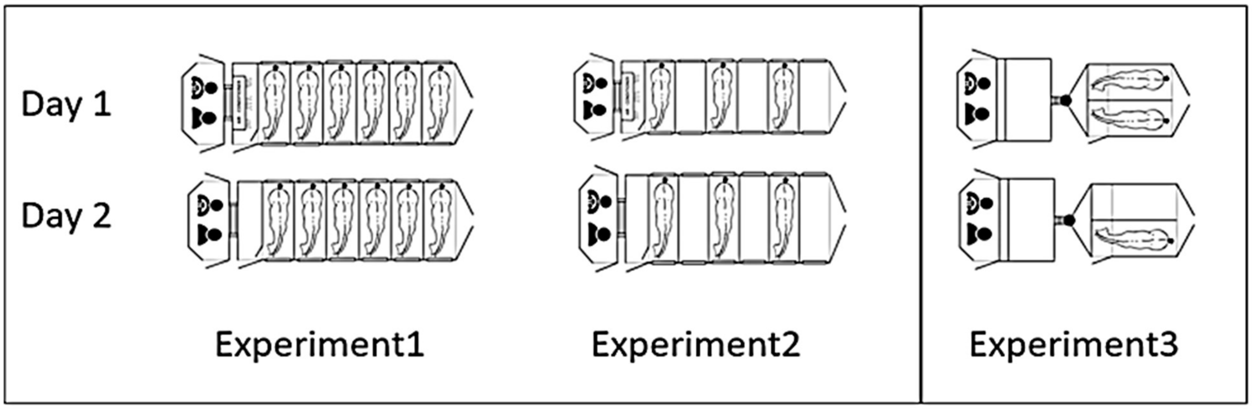

Figure 1 Diagram shows the position of the horses standing in the experiments. Day 1 of experiments 1 and 2 used an air-conditioning trailer, while Day 2 used a trailer without air-conditioning. Experiment 3 used a pulling-trailer without air-conditioning.

Transportation method

The six horses were repeatedly loaded and transported from the Horse Lover's Club, Patum thani 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 first 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. 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. 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. The third 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 third 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.

All vehicles were driven by licensed drivers who were very experienced in horse transportation. The vehicles were clean and disinfected with an antiseptic solution before and after transportation. Throughout each transportation, the horses were given pangola hay. the experiment procedure is showed in Table 1.

Table 1 Timeline and experimental design for the study

Types of vehicles	1st Week	2nd Week	3rd Week
Horse Air-Conditioning Truck (6 Horses; Full capacity)	→		
Horse Non-Air-Conditioning Truck (6 Horses; Full capacity)	→		
Horse Air-Conditioning Truck (3 Horses; Spacing capacity)		→	
Horse Non-Air-Conditioning Truck (3 Horses; Spacing capacity)			
Horse Air-Conditioning Truck (3 Horses; Spacing capacity)		→	
Horse Non-Air-Conditioning Truck (3 Horses; Spacing capacity)			
Horse Trailer (2 Horses; Full capacity)			→
Horse Trailer (1 Horse; Spacing capacity)			→

The distance of transportation was approximately 250 kilometers which lasted about 5 hours of transportation. These 250 kilometers distance travel is the average distance between the stable to commonly used competition venue in Thailand. All transportation were departed at the same time

Stage 1: Comparison of Horse Welfare

The objective of the stage 1 was to compare the horse welfare among different modes of transportation. To evaluate horse welfare, blood cortisol and heart rate were collected and statistically analyzed. Cortisol levels were analyzed using GraphPad Prism, version 9.3.1 (GraphPad

Software, California, USA). Shapiro-Wilk test was used to ensure normality. One-way ANOVA following by Tukey's multiple comparisons test was implemented to compare serum cortisol level within groups of comparison. Data were expressed as mean±SEM; $p<0.05$ was considered statistically significant.

Results

Blood cortisol level

Blood cortisol levels determined before transportation, immediately after transportation, 30 min and 90 min after transportation are demonstrated in table 1. Changes in the cortisol level in different condition are as follows;

Table 2 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 causes 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 2 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.

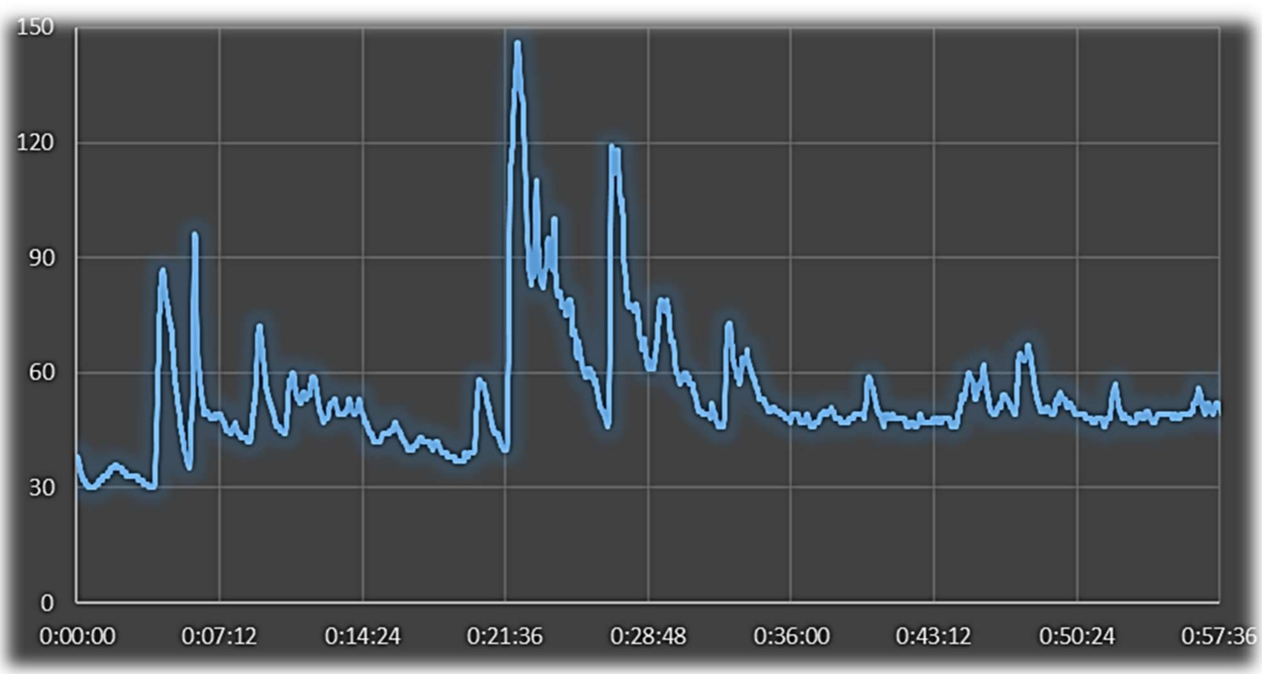

Figure 2 A sample of horse heart rate during 1 hour of transportation

Stage 2: Mathematical Model for Horse Transportation 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.

To construct a mathematical model, a mathematical programming was implemented.

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
	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)

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

$$\mathrm{Min} \sum c_i x_i + \lambda \mathrm{H}(J_i n_i x_i)$$

Constraints:

1. Every horse must be transported.

$$\sum n_i x_i = H$$

2. Capacity constraint: the transported horses cannot exceed the capacity of vehicle type *i*.

$$n_i x_i \leq Cap_i$$

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

n_i and $x_i \geq 0$ 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.

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 penalty of heart rate jump was estimated to be 100. The parameters and results were shown in Table 3.

Table 3 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	6.00	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	2.00	7500	1	1	5	5

The results showed that the total cost would be THB 125234 where the actual transportation costs would be THB 87500, while the penalty costs of poor welfare was 37734 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 3 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.

Discussion

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, our 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 3: parameter) 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.

Conclusions

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. The results showed that modes of transportation affected horse welfare where a transportation of small number of horses in air conditioning vehicle with enough space is preferred. Our study also developed a mathematical programming which was versatile and easy to use. The model was implemented in Excel and was well received. The benefit of the model helps the horse owners to select the most appropriate mode of transportation which helps maximize chances of winning.

Conflicts of interest - We declared no conflict of interest.

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