MODELING OF MOBILE TMR MIXER OPERATION
/
МОДЕЛИРОВАНИЕ РАБОТЫ МОБИЛЬНОГО КОРМОЦЕХА

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ABSTRACT

A method for determining the duration of the process of preparation and distribution of feed mixtures by a mobile mixer on cattle farms, based on graph theory, is proposed. A generalized state graph of the mobile mixer is presented and its description is given. The final formula for calculating the probability of the mobile mixer being in the state of distribution of a feed mixture consisting of a different number of components is given. To check the method adequacy, time-lapse measurements were performed in production conditions. The projected durability of the mobile mixer was 92.3% (0.36 h) of the actual recorded time of 0.39 h.

РЕЗЮМЕ

Предложена методика определения продолжительности процесса приготовления и раздачи кормосмесей мобильным кормоцехом на фермах крупного рогатого скота, основанная на теории графов. Представлен обобщенный граф состояний мобильного кормоцеха, дано его описание. Приведена итоговая формула для вычисления вероятности нахождения мобильного кормоцеха в состоянии раздачи кормосмеси, состоящей из различного количества компонентов. Для проверки адекватности методики проведены хронометражные замеры в производственных условиях. Прогнозируемая продолжительность работы мобильного кормоцеха составила 92.3 % (0.36 ч) от фактически зафиксированного времени 0.39 ч.

INTRODUCTION

Preparation and distribution of feed mixtures is one of the most time-consuming processes on cattle farms. For its implementation, the technology based on mobile mixers is widely used. An alternative technology that is becoming more common is the use of automatic feeding systems. A significant number of studies are devoted to comparative estimation of the effectiveness of these technologies *(Belle Z. et al, 2012; Oberschätzl-Kopp R. et al, 2016; Pezzuolo A. et al, 2016)*. Automatic feeding systems allow you to achieve a number of advantages compared to the mobile mixers utilization *(Da Borso F. et al, 2017; Kupreenko A.I. et al, 2019)*. One of the key advantages is the possibility of increasing the feeding frequency, which is evaluated in many studies on productivity and other indicators of animals (*Crossley R.E. et al, 2018; Hart K.D. et al, 2014; Mattachini G. et al, 2019).* Despite all the advantages, the main drawback of automatic feeding systems is the high cost of acquisition, which hinders their introduction into manufacturing (*Grothmann A. et al, 2010; Tangorra F.M. and Calcante A., 2018).* Therefore, the technology based on mobile mixers is still the main one.

Correctly selected mobile mixer for specific production conditions ensures the efficiency of the process of preparation and distribution of feed mixtures. For this choice, it is necessary to determine the animals feeding time, which must meet the established zootechnical standards in the farm. As practice shows, this time is influenced by a number of factors: load capacity (the volume of the mobile mixer hopper), livestock population maintained, the feeding frequency, the number of components in the feed mixture, the travel distances, etc.

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MATERIALS AND METHODS

When working, the mobile mixer spends time on cyclically repeated operations (cycle operating time) and operations related to its setting-up procedures, maintenance, employee rest, and others (off-cycle time). At the same time, due to possible technological violations and technical failures, the time spent on individual operations has probabilistic nature. The time of feed mixtures preparation and distribution on cattle farms, taking into account the probabilistic nature of the components of the operating time balance of the mobile mixer, is determined by the formula:

$$T_{\text{к.мк}} = T_{\text{c}} + T_{\text{oc}} = \frac{Nl_{\text{к}}}{p_p V_p} k_{\text{c}} + T_{\text{oc}} \le [T_{\text{к}}], \text{ [h]} \tag{1}$$

where: T_{c} – cycle time of one feeding, [h];

T_{oc} – off-cycle time of one feeding, [h];

N – number of animals maintained on the farm, [unit];

$l_{\text{к}}$ – length of one feed space, [km/unit];

k_{c} – coefficient that takes into account the loss of cycle time associated with the management of the technological process of preparation and distribution of feed mixtures;

p_p – the probability of the mobile mixer being in the state of distribution of the feed mixture (corresponds to the state S_{52} in figure 1);

V_p – movement rate of the mobile mixer during distribution, [km/h];

$T_{\text{к}}$ – the time permitted for one feeding according to zootechnical requirements, [h].

To calculate the probability p_p, that is part of the formula (1), a generalized graph of the mobile mixer states (figure 1) is developed. It permits to consider the preparation and distribution of feed mixtures by the mobile mixer at various number of components (parameter "x").

The transition from one state to another occurs under the action of random flows with intensities $\lambda_{i,j}$, indicated in the figure by arrows (for example, the transition from state S_1 to state S_2 is performed under the influence of a random flow with intensity $\lambda_{1,2}$). Their value is inverse ratio to the time spent on the operation performance in the S_i state. The probability of being in the S_i state is equal to p_{i}.

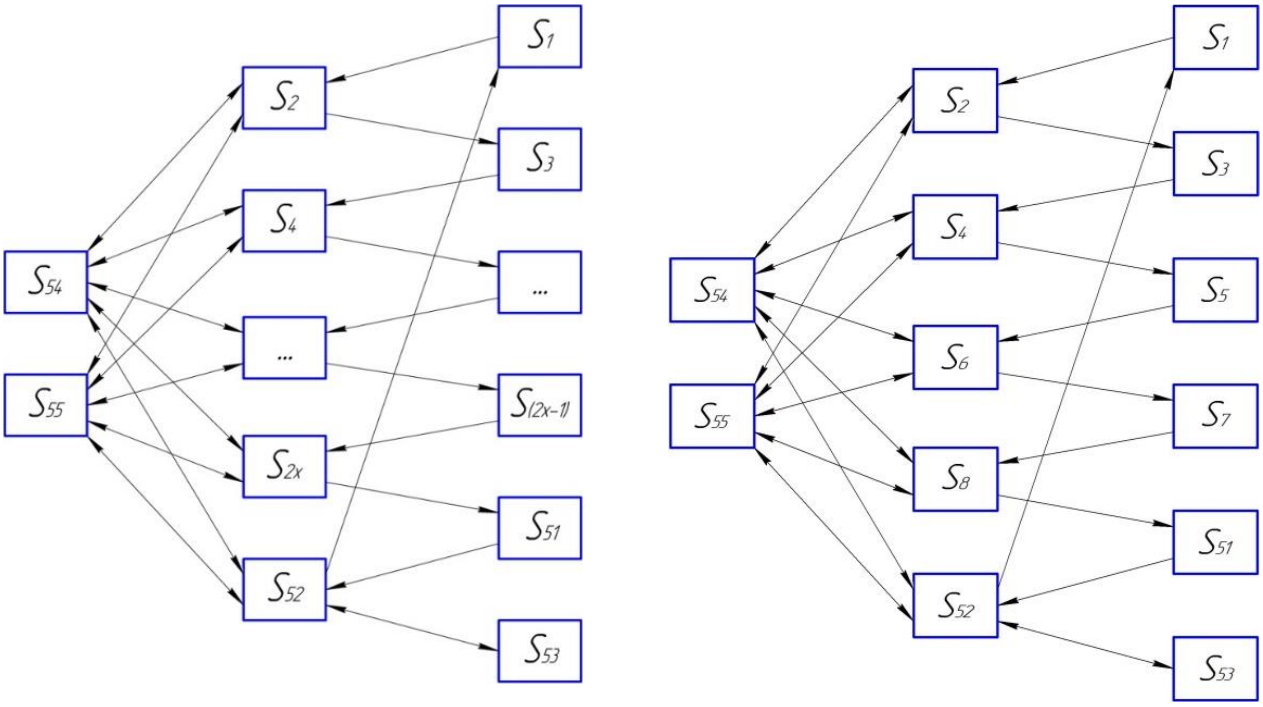

Fig. 1 - Generalized graph of the mobile mixer states (left) and graph for special case at *x* = 4 (right)

x - the number of components (types of feed) in the feed mix (to 25); S_1 - travel from the parking place to the storage facility with 1 component; $S_3 \ldots S_{(2x-1)}$ - travels of the mobile mixer between storages with components; $S_2, S_4 \ldots S_{2x}$ - loading of the feed mixture components; S_{51} - travel from storage with the last component to livestock facilities; S_{52} - feed mixture distribution; S_{53} - turning when traveling to another distribution line; S_{54} – technological breakdown; S_{55} - technical failure

$$\begin{cases} p_1\lambda_{1,2} = p_{52}\lambda_{52,1} \\ p_2(\lambda_{2,3}+\lambda_{2,54}+\lambda_{2,55}) = p_1\lambda_{1,2} + p_{54}\lambda_{54,2} + p_{55}\lambda_{55,2} \\ p_3\lambda_{3,4} = p_2\lambda_{2,3} \\ p_4(\lambda_{4,5}+\lambda_{4,54}+\lambda_{4,55}) = p_3\lambda_{3,4} + p_{54}\lambda_{54,4} + p_{55}\lambda_{55,4} \\ p_5\lambda_{5,6} = p_4\lambda_{4,5} \\ p_6(\lambda_{6,7}+\lambda_{6,54}+\lambda_{6,55}) = p_5\lambda_{5,6} + p_{54}\lambda_{54,6} + p_{55}\lambda_{55,6} \\ p_7\lambda_{7,8} = p_8\lambda_{8,51} \\ p_8(\lambda_{8,51}+\lambda_{8,54}+\lambda_{8,55}) = p_7\lambda_{7,8} + p_{54}\lambda_{54,8} + p_{55}\lambda_{55,8} \\ p_{51}\lambda_{51,52} = p_8\lambda_{8,51} \\ p_{52}(\lambda_{52,1}+\lambda_{52,53}+\lambda_{52,54}+\lambda_{52,55}) = p_{51}\lambda_{51,52} + p_{53}\lambda_{53,52} + p_{54}\lambda_{54,52} + p_{55}\lambda_{55,52} \\ p_{53}\lambda_{53,52} = p_{52}\lambda_{52,53} \\ p_{54}(\lambda_{54,2}+\lambda_{54,4}+\lambda_{54,6}+\lambda_{54,8}+\lambda_{54,52}) = p_2\lambda_{2,54} + p_4\lambda_{4,54} + p_6\lambda_{6,54} + p_8\lambda_{8,54} + p_{52}\lambda_{52,54} \\ p_{55}(\lambda_{55,2}+\lambda_{55,4}+\lambda_{55,6}+\lambda_{55,8}+\lambda_{55,52}) = p_2\lambda_{2,55} + p_4\lambda_{4,55} + p_6\lambda_{6,55} + p_8\lambda_{8,55} + p_{52}\lambda_{52,55} \\ \sum p_i = 1 \end{cases} \tag{2}$$

Expressions of transition intensities have the following form:

$\lambda_{1,2} = \dfrac{V_{emp}}{L_0}$, where: V_{emp} – the speed of the empty mobile mixer, [km/h], L_0 – distance from the parking place of the mobile mixer to the place of the first component loading;

$\lambda_{2,3} = \dfrac{Q_1}{M_1} \cdots \lambda_{8,51} = \dfrac{Q_4}{M_4}$, where: $Q_1 \ldots Q_4$ – loading efficiency of component 1-4, [t/h],

$M_1 \ldots M_4$ – corresponding weights of loaded components, [t].

$\lambda_{3,4} = \dfrac{V_l}{L_1} \cdots \lambda_{7,8} = \dfrac{V_l}{L_3}$, where: V_l – speed of loaded mobile mixer, [km/h],

$L_1 \ldots L_3$ – corresponding travel distances between storage locations with component 1-3;

$\lambda_{51,52} = \dfrac{V_l}{L_t}$, where: L_t – travel distance from the storage with the last loaded component to the distribution start point, [km];

$\lambda_{52,53} = \dfrac{2V_p m_p}{G_k l_k}$, where: V_p – speed of mobile mixer when distributing feed mixture, [km/h], m_p – one-time feed mixture allowance per head, [kg/head], $G_к$ – load capacity of the mobile mixer / the loaded weight of the feed mixture, [kg], $l_к$ – length of one feed space, [km/head];

$\lambda_{53,52} = \dfrac{1}{t_{tim}}$, where t_{tim} – time of turning when traveling to another distribution line, [h];

$\lambda_{52,1} = \dfrac{V_p m_p}{G_k l_k}$;

$\lambda_{2,54} = \ldots = \lambda_{52,54} = 1/T_{TH}$, where T_{TH} – running time for technological breakdown, [h];

$\lambda_{2,55} = \ldots = \lambda_{52,55} = 1/T_{TO}$, where T_{TO} – running time for technical failure, [h];

$\lambda_{54,2} = \ldots = \lambda_{54,52} = 1/T_{YTH}$, where T_{YTH} – technological breakdown clearing time, [h];

$\lambda_{55,2} = \ldots = \lambda_{55,52} = 1/T_{YTO}$, where T_{YTO} – technical failure clearing time, [h].

To find a general solution of Kolmogorov equation systems for any number of components in the feed mixture, the systems of equations were compiled for three special cases: x = 2, x = 3 and x = 4 (2 -, 3 - and 4 -component feed mixture).

When solving these systems, to simplify the transformations, we introduced the corresponding coefficients K_i to replace the combinations of intensities $\lambda_{i,j}$. Coefficients K_i make it possible to trace the change of each of them at different amounts of components in the feed mixture to establish the existing pattern. The process of solving these systems of equations as well as the established regularities are reflected in the paper *(Kupreenko A.I. et al, 2017)*.

Only the final formula for calculating the desired probability of finding a mobile mixer in the feed mixture distribution state for any number of components in the feed mixture is presented below:

$$p_{52} = p_{55} \frac{K_{54}^{x\Sigma}\ K_{52}^{x\text{б}} + K_{52}^{x\text{в}}}{K_{52}^{xa}}, \tag{3}$$

where:

$$p_{55} = \frac{K_{52}^{x\text{a}}}{K_{52}^{xa} + (K_{54}^{x\Sigma}\ K_{52}^{x\text{б}} + K_{52}^{x\text{в}})K_{55}^{xa} + K_{54}^{x\Sigma}\ K_{55}^{x\text{б}} K_{52}^{x\text{a}} + K_{55}^{x\text{в}} K_{52}^{xa}} \tag{4}$$

These expressions are unchanged for any value of x. Herewith, the content of each of the coefficients K_i of expressions (3) and (4) is characterized by the absence of unknown values of incoming variables and with the change of the value of x, it changes in a certain sequence.

The established regularities in the form of a mathematical model are implemented in the MS Excel program. This completely eliminates the need to create graphs of states and the Kolmogorov systems of equations, their further manual solution, and reduces the entire task of determining the duration of the process of preparation and distribution of feed mixtures by the mobile mixer to a simple input of initial data. The correctness of the calculations is confirmed by the convergence of the final values for the 5 - component feed mixture in mathematical modeling in MS Excel and manual solution.

To check the adequacy of the developed methodology, time-lapse measurements of the mobile mixer operation "Storti Husky MT 90" in aggregation with a tractor "Belarus 1221" were carried out at the dairy farm of SEC-Agrofirma "Kultura" in the village of Dobrun, Bryansk region (Russia).

The feed loading time was determined by video recording the process.

The performance of the loading line was determined by dividing the mass of loaded components by the fixed loading time.

Distances and travel times were determined by recording the track of the completed route in the Strava mobile app (fig. 2). Here, in addition, the loading time of components was checked according to the idle time of the unit.

The length of a single feed space was defined as the ratio of the total length of the feed table to the number of animals placed along it.

The one-time feed mixture allowance per head was defined as the ratio of the total mass of feed mixture in the hopper to the number of animals maintained.

The GPS signal required for the mobile application operation was absent in the cowshed. Therefore, the feed table length was determined by the delivery time, which was recorded during the video recording, and the tractor speed, which was constant and was 2 km/h according to the information displayed on the tractor monitor.

In the proposed method, the speed of movement of a loaded mobile mixer is assumed to be constant. In practice, it varies within certain limits. The maximum recorded speed of a loaded mobile mixer when traveling was 9 km/h. In other cases, at a lower recorded speed, the distance for entering data was calculated as the product of the time spent on the move and the maximum speed (9 km/h).

RESULTS

According to the time-metering, the following values are obtained:

1) flour loading in the feed storage facility from the tower hopper (422 kg, 01 min 55 s): Q = 13.2 t/h;
2) travel from storage facility (20 m in 00 min 35 s): V = 2.06 km/h
3) concentrates loading in the storage facility by a tractor with a bucket (298 kg, 04 min 30 s): Q = 3.97 t/h;
4) travel to a silage trench (150 m in 00 min 59 s): V = 9 km/h;
5) silage loading from a trench by a tractor with a bucket (3032 kg, 06 min 38 s): Q = 27.43 t/h;
6) travel to storage facility with molasses (200 m, 02 min 03 s): V = 5.85 km/h;
7) molasses loading (156 kg, 01 min 16 s): Q = 7.39 t/h;
8) travel to molasses (230 m, 01 min 52 s): V = 7.4 km/h.

The number of the maintained animals is 90 heads, daily allowance of delivery – 43.42 kg/heads.

Duration of single cycle of feed mixture preparation and distribution was 0.39 h (fig. 2): components loading – 0.24 h (61.5 %); travels – 0.09 h (23.1 %); delivery – 0.03 h (7.7 %); cycle time losses – 0.03 h (7.7 %).

The following parameters were used for modeling:

- the load capacity of the mobile mixer $G_к$ = 3908 kg (numerically equal to the weight of the loaded ration components);
- the component number in the feed mixture x = 4;
- the time of daily maintenance (ETO) of the mobile mixer T_{ETO} = 0.00001 hours (since the division by "0" is not possible in the compiled program, a value close to zero was selected);

a) b) c)

Fig. 2 – Mobile TMR mixer Storti Husky MT 90 (a), Routing track, recorded in mobile application «Strava» (b) and Constituents of time balance of the mobile mixer operating cycle (c)

- the number of the maintained animal (for one cycle) N = 90 heads;
- the speed of the loaded mobile mixer and the speed during delivery correspondingly V_l = 9 km/h and V_p = 2 km/h;
- flour loading efficiency, concentrates, silage and molasses, respectively Q_1 = 13.2 t/h, Q_2 = 3.97 t/h, Q_3 = 27.43 t/h and Q_4 = 7.39 t/h;
- the mass fractions of these components in the feed mixture, respectively m_1 = 0.108, m_2 = 0.076, m_3 = 0.776 and m_4 = 0.04;
- equivalent traveling distances in terms of movement at a speed of 9 km/h: mixer ➔ street L_2 = 87.5 m (traveling distance from the parking place to the loading place of the first component L_1 = 0), street ➔ trench L_3 = 150 m, trench ➔ molasses L_4 = 307.5 m, molasses ➔ cowshed L_p = 280 m;
- one-time feed mixture allowance per head m_p = 43.42 kg;
- length of one feed space $l_к$ = 0.63 m;
- time of turning for distribution to the second row T_t = 0.000001 h;
- coefficient that takes into account the losses of cycle time k_c = 1;
- in the mean running time for technological breakdown, elimination of technological breakdown; running time for technical failure and elimination of technical failure the following values were accepted: respectively, T_{TH} = 10 h, T_{YTH} = 0.2 h, T_{TO} = 250 h and T_{YTO} = 5 h. The modeling results showed that when changing the values of parameters T_{TH} and T_{YTH} in the range of 1-50 respectively and 0.1-0.5 h the value of feeding time $T_{K.MK}$ is in the range of 0.36-0.38 h; as a result of changing the values of parameters T_{TO} and T_{YTO} within the range of 50-500 and 1-25 h, respectively, the value of the feeding time $T_{K.MK}$ is in the range of 0.36-0.39 h.

According to the results of the modeling (table 1) with the probability of finding a mobile fixer in the state of distribution of feed mixture p_{52} = 0.079 the value of the feeding time $T_{K.MK}$ was 0.36 h (-7.7 % compared to the actual feeding time).

Table 1

Modeling results in MS Excel

p_1	0.00000	p_{51}	0.08596	$T_{K.MK}$ [h]	0.36
p_2	0.08918	p_{52}	0.07915	N [cows]	90
p_3	0.02712	p_{53}	0.00001	$n_к$ [pc]	0.18
p_4	0.20774	p_{54}	0.00590	$[T_к]$ [h]	2
p_5	0.04628	p_{55}	0.00295	n_c [cycle]	1
p_6	0.30348			Q_{ch} [t/h]	10.85
p_7	0.09379				
p_8	0.05845				

Thus, the adequacy of the proposed mathematical model for determining the time of feeding animals with a mobile mixer on cattle farms is confirmed by the results of timekeeping measurements in production conditions. The study showed that the predicted feeding time was 92.3% of the actual one.

CONCLUSIONS

The use of the proposed method in practice will allow you to make a reasonable choice of appropriate equipment for feeding in specific production conditions, expand the capabilities of personnel in the work organization.

The method adequacy is confirmed by the high accuracy of convergence of timekeeping measurements' results of the mobile mixer in production conditions and modeling. Studies have shown that the predicted feeding time was 92.3% of the actual one.

The main criterion for selecting the required load capacity of the mobile mixer is the permissible duration of animal feeding. The low load capacity of the mobile mixer increases the number of cycles of preparation of feed mixture while reducing the duration of one cycle and vice versa. The next task is to determine the optimal load of the mobile mixer within the possible range of changes in basic input data, the number of animals on the farm, feed mixture allowance.

The further important task is to determine the conditions when the use of two mobile mixers with a small load capacity will be more cost-effective than using one mobile mixer with a high load capacity.

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