MODELLING OF MOBILE TMR MIXER OPERATION
/ МОДЕЛИРОВАНИЕ РАБОТЫ МОБИЛЬНОГО КОРМОЦЕХА

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DOI: https://doi.org/10.35633/inmateh-61-21

Keywords: feeding, mobile mixer, graph theory, timekeeping

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.

REЗЮМЕ
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:

\[ T_{MK} = T_c + T_{oc} = \frac{Nl_k}{p_r V_p} k_c + T_{oc} \leq \left[T_c\right] \ [h] \] (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];
- \( l_k \) – 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;
- \( p_r \) – 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];
- \( T_k \) – the time permitted for one feeding according to zootechnical requirements, [h].

To calculate the probability \( p_r \), 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 \( p_i \).

\[ \text{Fig. 1 - Generalized graph of the mobile mixer states (left) and graph for special case at } x = 4 \text{ (right)} \]

\( x \) - 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; \( S_3 \) - traveling between storages with components; \( S_2, S_4, S_5 \) - 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
Expressions of transition intensities have the following form:

$$\lambda_{3,2} = \frac{V_{\text{mp}}}{t_{\text{n}}}, \text{ where: } V_{\text{mp}} - \text{the speed of the empty mobile mixer, [km/h]}, \text{ } L_{0} - \text{distance from the parking place of the mobile mixer to the place of the first component loading; }$$

$$\lambda_{3,2} = \frac{Q_{1}}{M_{1}} \ldots \lambda_{8,51} = \frac{Q_{4}}{M_{4}}, \text{ where: } Q_{1} \ldots Q_{4} - \text{loading efficiency of component 1-4, [t/h], }$$

$$M_{1} \ldots M_{4} - \text{corresponding weights of loaded components, [t].}$$

$$\lambda_{3,4} = \frac{V_{1}}{L_{4}} \ldots \lambda_{7,8} = \frac{V_{7}}{L_{8}}, \text{ where: } V_{l} - \text{speed of loaded mobile mixer, [km/h], }$$

$$L_{1}, \ldots L_{4} - \text{corresponding travel distances between storage locations with component 1-3; }$$

$$\lambda_{5,52} = \frac{V_{l}}{L_{1}}, \text{ where: } L_{l} - \text{travel distance from the storage with the last loaded component to the distribution start point, [km]; }$$

$$\lambda_{5,52} = \frac{2V_{p}m_{p}}{G_{c}t_{\text{lim}}}, \text{ where: } V_{p} - \text{speed of mobile mixer when distributing feed mixture, [km/h]}, m_{p} - \text{one-time feed mixture allowance per head, [kg/head], } G_{c} - \text{load capacity of the mobile mixer / the loaded weight of the feed mixture, [kg]}, l_{c} - \text{length of one feed space, [km/head]; }$$

$$\lambda_{5,52} = \frac{1}{t_{\text{lim}}} \text{, where } t_{\text{lim}} - \text{time of turning when traveling to another distribution line, [h]; }$$

$$\lambda_{5,52} = \frac{V_{p}}{G_{c}t_{\text{lim}}};$$

$$\lambda_{2,54} = \ldots = \lambda_{3,54} = 1/T_{TH}, \text{ where } T_{TH} - \text{running time for technological breakdown, [h]; }$$

$$\lambda_{2,55} = \ldots = \lambda_{3,55} = 1/T_{TO}, \text{ where } T_{TO} - \text{running time for technical failure, [h]; }$$

$$\lambda_{5,42} = \ldots = \lambda_{5,45} = 1/T_{TH}, \text{ where } T_{TH} - \text{technological breakdown clearing time, [h]; }$$

$$\lambda_{5,52} = \ldots = \lambda_{5,55} = 1/T_{TO}, \text{ where } T_{TO} - \text{technical failure clearing time, [h]. }$$

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 \( K \), to replace the combinations of intensities \( \lambda_{i} \). Coefficients \( K \) 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:
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 \( G_c = 3908 \) 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);
- 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 \( \rightarrow \) street \( L_2 = 87.5 \) m (traveling distance from the parking place to the loading place of the first component \( L_1 = 0 \)), street \( \rightarrow \) trench \( L_3 = 150 \) m, trench \( \rightarrow \) molasses \( L_4 = 307.5 \) m, molasses \( \rightarrow \) cowshed \( L_p = 280 \) m;
- one-time feed mixture allowance per head \( m_p = 43.42 \) kg;
- length of one feed space \( l_c = 0.63 \) 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).

![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)](image)

| Modeling results in MS Excel | \( p_1 \) | 0.000000 | \( p_{51} \) | 0.085966 | \( T_{K.MK} \) [h] | 0.36 |
|-----------------------------|-----------|-----------|------------|----------|----------------|-----|
| \( p_2 \)                   | 0.08918   | \( p_{52} \) | 0.07915    | \( N \) [cows] | 90 |
| \( p_3 \)                   | 0.02712   | \( p_{53} \) | 0.00001    | \( N_c \) [pc] | 0.18 |
| \( p_4 \)                   | 0.20774   | \( p_{54} \) | 0.00590    | \( T_t \) [h] | 2 |
| \( p_5 \)                   | 0.04628   | \( p_{55} \) | 0.00295    | \( n_c \) [cycle] | 1 |
| \( p_6 \)                   | 0.30348   | \( \theta \) | 10.85      | \( Q_{ch} \) [t/h] | 10.85 |
| \( p_7 \)                   | 0.09379   | \( \theta_1 \) |          | \( \theta_2 \) | 1 |
| \( p_8 \)                   | 0.05845   | \( \theta_2 \) |          | \( \theta_3 \) | 1 |
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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