Formation of mixes with specified characteristics from the available small batches of multicomponent mixes, subject to their full use

A V Evseev¹, A A Alekseev², G V Kasatkin², V V Preys¹
¹Tula State University, Tula, Russia
²MIREA – Russian Technology University, Moscow, Russia

E-mail: ews1972@mail.ru

Abstract. Methods, decision algorithms and examples of tasks of new mixes formation with the set characteristics from the available small batches of components or mixes are given in this research. This analysis continues previous researches by the authors on the formation of mixes with specified quality characteristics. This article presents a solution technique, algorithms, and corresponding examples of tasks for the formation of new mixtures, provided that some small batches of mixes or components must be spent completely. Technique and technology solutions of these tasks can be of interest and to be demanded in the different industries of production, for example, at production of premixes for livestock production, at preparation of different food mixes, products and additives, medicines, metal powder materials, in construction, in military industry, by production of thixotropic mixes, fertilizers, household chemicals and in many other technology processes.

1. Introduction
In technological processes of the general mix production of several small consignments of multicomponent mixes or separate similar components there can be situations when the general mix needs to be synthesized from certain remains of small batches or components in view of impossibility of their processing or utilization [1-5]. It can be also connected with storage lives or with need to make room for new small batches or components. Thus, there is the need of mathematical justification of the technology problem of synthesis of the general mix from the remained stocks of small batches or components. At the same time it is required to use residual stocks in some optimum way so that the received new mixes met criteria of quality of mixes, demanded by the customer [6-10]. This problem is solved for the first time that defines its scientific novelty and has important applied value for many industries of the national economy.

2. Problem definition
In technology process of production of new mix of several small consignments of multicomponent mixes or components with different properties and volumes there are different questions demanding them permission mathematical means.
Let's consider the following situation.
There are available:
n mixes: \( A_1, \ldots, A_n \), which containing (in addition to insignificant components) \( k \) significant components: \( B_1, \ldots, B_k \); where \( a_1, \ldots, a_n \) – are volumes (masses) of mixes \( A_1, \ldots, A_n \) respectively; \( b_{ij} \) – are relative maintenance (concentration) of the component \( B_j \) \((i = 1..k)\) in mix \( A_j \), \((j = 1..n)\), i.e. relation of the volume (weight) of the component \( B_i \) to the volume (weight) of mix \( A_j \), in condition:

\[
0 \leq b_{ij} \leq 1, \quad \sum_{j=1}^{k} b_{ij} \leq 1.
\]

From mixes \( A_1, \ldots, A_n \) new mix \( A \) forms as follows: mixes \( A_{l+1}, \ldots, A_n \) \((1 \leq l < n)\) completely join in mix \( A \), to which parts of mixes are added \( A_1, \ldots, A_l \) in the form of volumes \( x_1, \ldots, x_l \).

In this case, concentration \( b_1, \ldots, b_k \) components \( B_1, \ldots, B_k \) in mix \( A \) are defined by the system of equations:

\[
\begin{aligned}
\sum_{j=1}^{l} b_{ij}' x_j + \sum_{j=l+1}^{n} b_{ij}' a_j = b_i \left( \sum_{j=1}^{l} x_j + \sum_{j=l+1}^{n} a_j \right),
\end{aligned}
\]

\((1)\)

Set of sizes \( x_1, \ldots, x_l \) represents coordinates of the point of the rectangular parallelepiped \( \Pi_x = \{(x_1, \ldots, x_l) \mid 0 \leq x_1 \leq a_1; 0 \leq x_2 \leq a_2; \ldots; 0 \leq x_l \leq a_l\} \), \( l \) – measured space with the Cartesian coordinate system \( O_{x_1, x_2, \ldots, x_l} \), and set of numbers \( b_1, \ldots, b_k \) – are coordinates of the point of \( k \) – measured parallelepiped \( \Pi_b = \{\left(b_1, \ldots, b_k\right) \mid b_{ij}' \leq b_1 \leq b_1^*; \ldots; b_{ij}' \leq b_k \leq b_k^*\} \), where \( b_{ij}' = \min\{b_{ij}'\}, \quad b_i^* = \max\{b_i^*\} \quad i=1..k, \quad j=1..n \).

When forming the specified mix \( A \), it is necessary to solve the following tasks.
1. Whether it is possible the choice of masses \( x_1, \ldots, x_l \) of mixes \( A_1, \ldots, A_l \) to receive mix \( A \) with preset concentration values \( b_1, \ldots, b_k \)? If yes, what at the same time are possible mix volumes \( A \)?
2. If the first issue is resolved negatively, then what it is possible to make mix with the closest values \( b_1, \ldots, b_k \) to desired values \( \bar{b}_1^*, \ldots, \bar{b}_k^* \), and what at the same time it is possible to receive mix volumes \( A \)?
3. Whether it is possible the choice of masses \( x_1, \ldots, x_l \) mixes \( A_1, \ldots, A_l \) to make mix \( A \) with the set relation of concentration \( b_1 : b_2 : \ldots : b_k = q_1 : q_2 : \ldots : q_n \). If yes, that what maximum values of sizes \( b_1, \ldots, b_k \), and what volumes of mix answer them?
4. If the third issue is resolved negatively, then what most close relation \( b_1 : b_2 : \ldots : b_k \) to the set relation \( q_1 : q_2 : \ldots : q_n \) it is possible to achieve and what volumes of mix \( A \) at the same time it is possible to receive?

All questions formulated here are the statements of tasks 1-4 connected with search of extremum of the corresponding functions in the limited closed areas \([11]\).

3. Theory. Algorithms of the solution tasks

Task 1. At preset values of concentration \( b_1, \ldots, b_k \) the system (1) represents the linear heterogeneous system concerning unknown \( x_1, \ldots, x_l \).

The problem is solved only if this system jointly and has decisions in the parallelepiped \( \Pi_x \).
If decision \((x_1, \ldots, x_l)\) system (1) is unique and belongs to the set \(\Pi_x\), then the received volume
\[
V = \sum_{j=1}^l x_j + \sum_{j=l+1}^n a_j
\]
will be unique.

If the solution of system (1) is unique and belongs to the set, the resulting volume will be unique. If common decision of system (1)
\[
\begin{align*}
\begin{cases}
x_j = \sum_{\lambda=1}^m q_j^\lambda c_\lambda + q_j^x, \\
0 \leq x_j = \sum_{\lambda=1}^m q_j^\lambda c_\lambda + q_j^x \leq a_j,
\end{cases}
\end{align*}
\]
has the set of decisions
\[
\Omega = \{(c_1, \ldots, c_m) \mid c_i^j \leq c_\lambda \leq c_i^{x^*}, \lambda = 1, m\},
\]
that all possible volumes of mix will be defined by the equation
\[
V = \sum_{i=1}^l \left(\sum_{\lambda=1}^m q_j^\lambda c_\lambda + q_i^x\right) + \sum_{j=l+1}^n a_j = f(c_1, \ldots, c_m).
\]
The largest and smallest volume of mix is answered by points of the minimum and the maximum of function \(f(c_1, \ldots, c_m)\) in the area \(\Omega\).

Example 1. There are mixes \(A_1, \ldots, A_5\) with two components \(B_1, B_2\). Volumes of mixes and concentration of components are respectively equal in them
\[
a_1 = 3.8, \quad a_2 = 1.4, \quad a_3 = 4.2, \quad a_4 = 3, \quad a_5 = 2,
\]
\[
b_1^1 = 0.11, \quad b_1^2 = 0.2, \quad b_1^3 = 0.15, \quad b_1^4 = 0.14, \quad b_1^5 = 0.13,
\]
\[
b_2^1 = 0.28, \quad b_2^2 = 0.22, \quad b_2^3 = 0.25, \quad b_2^4 = 0.18, \quad b_2^5 = 0.19.
\]
On condition of full expenditure of mixes \(A_1, A_5\) it is required to make new mix of the specified mixes \(A\) with concentration of components \(b_1 = 0.14, b_2 = 0.22\). If it is feasible, then what are possible mix volumes?

The decision we will pass according to the stated algorithm decisions of the task 1.

For these values of concentration of the equation (1) will register in the look
\[
\begin{align*}
\begin{cases}
0.11x_1 + 0.2x_2 + 0.15x_3 + 0.14x_3 + 0.13x_2 = 0.14(x_1 + x_2 + x_3 + 3 + 2) \\
0.28x_1 + 0.22x_2 + 0.25x_3 + 0.18x_3 + 0.19x_2 = 0.22(x_1 + x_2 + x_3 + 3 + 2)
\end{cases}
\end{align*}
\]
The received system has the common decision from one arbitrary constant \(c_1\), representable in the look
\[
\begin{align*}
x_1 &= c_1 \\
x_2 &= \frac{5}{6} c_1 - \frac{2}{3} \\
x_3 &= 6 - 2c_1
\end{align*}
\]
System of inequalities
leads to the following set of permissible values of size \( c_1 \),
\[
c_1 \in \Omega = \{0.9 \leq c_1 \leq 2.48\}.
\]
As a result, we come to the following conclusions.
1. Required mix can be made.
2. All volumes of mix are from the equation
\[
V = x_1 + x_2 + x_3 + a_4 + a_5 = c_1 + \left( \frac{5}{6} c_1 - \frac{2}{3} \right) + \left( 6 - 2c_1 \right) + 3 + 2 = - \frac{1}{6} c_1 + \frac{31}{3}, \quad 0.9 \leq c_1 \leq 2.48.
\]
3. The smallest volume of mix answers value \( c_1 = 2.48 \) also it is equal \( 9.92 \). It turns out at values \( x_1 = 2.48, \ x_2 = 1.4, \ x_3 = 1.04 \).
4. The largest volume of mix answers value \( c_1 = 0.9 \) also it is equal \( \frac{611}{60} \approx 10.18 \). It turns out at values \( x_1 = 0.9, \ x_2 = \frac{1}{12}, \ x_3 = 4.2 \).

**Task 2.** From the system (1) we find possible values of concentration of mix components \( A \)

\[
b_i = \frac{\sum_{j=1}^{l} b_j x_j + \sum_{j=l+1}^{n} b_j a_j}{\sum_{j=1}^{l} x_j + \sum_{j=l+1}^{n} a_j}, \quad i = 1, k.
\]  

Proximity of sizes \( b_1, ..., b_k \) to preset values \( b_1^*, ..., b_k^* \) let's evaluate by means of function

\[
f = |b_1 - b_1^*| + ... + |b_k - b_k^*|.
\]

Point \( (x_1, ..., x_l) \in \Pi_x \), in which this function accepts the minimum value, allows finding required values of concentration of components of mix \( A \) and its volume.
Example 2. There are mixes \( A_1, A_2, A_3, A_4 \) with two components \( B_1, B_2 \). Volumes of mixes and concentration of components are respectively equal in them
\[
a_1 = 4.4, \ a_2 = 3.8, \ a_3 = 5.2, \ a_4 = 3.6,
\]
\[
b_1^1 = 0.2, \ b_1^2 = 0.3, \ b_1^3 = 0.4, \ b_1^4 = 0.5,
\]
\[
b_2^1 = 0.4, \ b_2^2 = 0.2, \ b_2^3 = 0.3, \ b_2^4 = 0.1.
\]

From these mixes it is required to receive new mix \( A \) with the concentration of components, the closest to values \( b_1 = 0.33, \ b_2 = 0.29 \) on condition of full expenditure of mix \( A_4 \).

Decision. From the system (1) we find
\[ b_1 = \frac{1.8 + 0.2x_1 + 0.3x_2 + 0.4x_3}{3.6 + x_1 + x_2 + x_3}, \quad b_2 = \frac{0.36 + 0.4x_1 + 0.2x_2 + 0.3x_3}{3.6 + x_1 + x_2 + x_3}, \]

where \((x_1, x_2, x_3) \in \Pi_x = \{0 \leq x_1 \leq 4.4, \ 0 \leq x_2 \leq 3.8, \ 0 \leq x_3 \leq 5.2\}\). Comparison of the received expressions \(b_1\) and \(b_2\) with sizes 0.33 and 0.29 shows:

1) \(b_1 \geq 0.33\) in the area

\[ \Omega_1 = \{0 \leq x_1 \leq 4.4; 0 \leq x_2 \leq 3.8; 0 \leq x_3 \leq 5.2; \ 61.2 - 13x_1 - 3x_2 + 7x_3 \geq 0\}, \]

representing the convex polyhedron \(OKLMNP\), \(K1M1P1\) with tops

\[ O(x_1 = 0, x_2 = 0, x_3 = 0), \]

\[ K(x_1 = 4.4, x_2 = 0, x_3 = 0), \]

\[ L \left(x_1 = 4.4, x_2 = \frac{4}{3}, x_3 = 0\right), \]

\[ M_2(x_1 = 4.4, x_2 = 3.8, x_3 = 0), \]

\[ N \left(x_1 = \frac{249}{65}, x_2 = 3.8, x_4 = 0\right), \]

\[ P(x_1 = 0, x_2 = 3.8, x_4 = 0), \]

\[ O_1(x_1 = 0, x_2 = 0, x_3 = 5.2), \]

\[ K_1(x_1 = 4.4, x_2 = 0, x_3 = 5.2), \]

\[ M_1(x_1 = 4.4, x_2 = 3.8, x_3 = 5.2), \]

\[ P_1(x_1 = 0, x_2 = 3.8, x_3 = 5.2). \]

2) \(b_1 \leq 0.33\) in the area

\[ \Omega_2 = \left[0 \leq x_1 \leq 4.4; \frac{4}{3} \leq x_2 \leq 3.8; 0 \leq x_3 \leq \frac{37}{35}; \ 61.2 - 13x_1 - 3x_2 + 7x_3 \leq 0\right], \]

representing the triangular pyramid \(LMNM_2\) with tops \(M(x_1 = 4.4, x_2 = 3.8, x_3 = 0)\) and \(L, M_2, N\), stated above.

3) \(b_2 < 0.29\) in all points of the parallelepiped \(\Pi_x\).

Function \(f = \|b_1 - 0.33\|^2 + \|b_2 - 0.29\|^2\) in the area \(\Omega_1\) takes the form:

\[ f = b_1 - 0.33 + 0.29 - b_2 = \frac{1.296 - 0.24x_1 + 0.06x_2 + 0.06x_3}{3.6 + x_1 + x_2 + x_3}, \]

and in the area \(\Omega_2\)

\[ f = 0.33 - b_1 + 0.29 - b_2 = \frac{0.072 + 0.02x_1 + 0.12x_2 - 0.08x_3}{3.6 + x_1 + x_2 + x_3}. \]

The subsequent calculations showed that the minimum value of function \(f\), equal 0.03, is accepted in top \(K\), i.e. at \(x_1 = 4.4, x_2 = 0, x_3 = 0\). At the same time volume turns out \(V = 8\) mixes \(A\) with concentration \(b_1 = 0.335, b_2 = 0.265\) components \(B_1, B_2\).

**Task 3.** We make the following system of equations of the system (1)

\[
\begin{aligned}
&\sum_{j=1}^{l} b_j^1 x_j + \sum_{j=l+1}^{n} b_j^1 a_j = b_k^1 \left( \sum_{j=1}^{l} b_j^k x_j + \sum_{j=l+1}^{n} b_j^k a_j \right) \\
&i = 1, \ldots, k - 1
\end{aligned}
\]

The objective has the decision when there is at least one decision \((x_1, \ldots, x_f)\) this system, belonging to the set \(\Pi_x\).

1. If such decision only, then set of required values of sizes \((b_1, \ldots, b_k)\), also as well as the volume of the received mix answering to them \(A\).
2. If such a solution is the only one, i.e. is representable in the form of (2) with restrictions (3), then sets of concentration \((b_1, \ldots, b_k)\), satisfying the desired relationship are not the only. They turn out after substitution of expressions (2) in formula (5) and give functions \(b_i = b_i (c_1, \ldots, c_m)\), where \((c_1, \ldots, c_m) \in \Omega\).

In this case, to find the maximum and minimum values of concentration it is enough to find the point \((c_1^*, \ldots, c_m^*)\) maximum and point \((c_1^\circ, \ldots, c_m^\circ)\) minimum of one function \(b_i (c_1, \ldots, c_m)\) in the area \(\Omega\).

After finding of the specified points volumes are calculated \(V_*, V_\circ\) new mix \(A\), answering to points \((c_1^*, \ldots, c_m^*)\), \((c_1^\circ, \ldots, c_m^\circ)\) and the sets corresponding to them \((x_1^*, \ldots, x_j^*)\) \((x_1^\circ, \ldots, x_j^\circ)\) the taken volumes from mixes \(A_1, \ldots, A_j\) for receiving mix \(A\).

Example 3.1. There are mixes \(A_1, A_2, A_3, A_4\) with components \(B_1, B_2, B_3\). Volumes of these mixes and concentration of components are respectively equal in them

\[
\begin{align*}
a_1 &= 7.6, & a_2 &= 5.4, & a_3 &= 4.0, & a_4 &= 2.4, \\
b_1^1 &= 0.26, & b_1^2 &= 0.18, & b_1^3 &= 0.15, & b_1^4 &= 0.23, \\
b_2^1 &= 0.12, & b_2^2 &= 0.09, & b_2^3 &= 0.08, & b_2^4 &= 0.13, \\
b_3^1 &= 0.25, & b_3^2 &= 0.17, & b_3^3 &= 0.17, & b_3^4 &= 0.24.
\end{align*}
\]

It is required to make new mix of these mixes \(A\) with the relation of concentration of components \(b_1 : b_2 : b_3 = 2 : 1 : 2\) on condition of full expenditure of mixes \(A_3, A_4\).

Decision. Under the set conditions the system (6) takes the form

\[
\begin{align*}
0.26x_1 + 0.18x_2 + 1.152 &= 0.25x_1 + 0.17x_2 + 1.256 \\
0.12x_1 + 0.09x_2 + 0.632 &= 0.5(0.25x_1 + 0.17x_2 + 1.256).
\end{align*}
\]

Calculations show that all solutions of the objective are represented by the system

\[
\begin{align*}
x_1 &= c_1, \\
x_2 &= -12 + 3c_1, \\
x_3 &= -7.2 + 2c_1
\end{align*}
\]

where \(c_1 \in \Omega = \{4.0 \leq c_1 \leq 5.6\}\).

The received decision results in the following possible concentration of components

\[b_1 = b_3 = 2b_2 = \frac{1.1c_1 - 2.688}{6c - 16.8}.
\]

Maximum values of concentration \(b_1, b_2, b_3\) mixes \(A\) turn out at value \(c_1 = c_1^* = 4\) also are equal \(b_1 = b_3 = \frac{107}{450} \approx 0.238, b_2 = \frac{107}{900} \approx 0.119\). The volume of mix with the specified values of concentration is equal 7.2 is formed from volumes \(x_1 = 4, x_2 = 0, x_3 = 0.8\), mixes \(A_1, A_2, A_3\).

Minimum values of concentration \(b_1, b_2, b_3\) in mix \(A\) turn out at value \(c_1 = c_1^\circ = 5.6\) also are equal \(b_1 = b_3 = \frac{217}{1050} \approx 0.207, b_2 = \frac{217}{2100} \approx 0.104\).

The volume of mix with the specified values of concentration is equal 16.8 also it from volumes is formed \(x_1 = 5.6, x_2 = 4.8, x_3 = 4\), mixes \(A_1, A_2, A_3\).
Task 4. Now the system of equations (6) has no decisions in the parallelepiped $\Pi_x$ at the relation of concentration of components $b_1 : b_2 : \ldots : b_k = q_1 : q_2 : \ldots : q_k$.

Let's designate:

$$\frac{q_i}{q_k} = \lambda_i, \quad i = 1, \ldots, k - 1.$$  

Let's enter function

$$f(x_1, \ldots, x_f) = \sum_{i=1}^{k-1} \frac{b_i}{b_k} - \lambda_i = \sum_{j=1}^{l} \frac{b_j}{b_k} x_j + \sum_{j=l+1}^{n} \lambda_j a_j,$$

by means of which we will estimate proximity of the relation $b_1 : b_2 : \ldots : b_k$ to the set relation $q_1 : q_2 : \ldots : q_k$.

We consider that to the required decision the minimum value of the specified function brings in the parallelepiped $\Pi_x$. Let $\{x_1 = x_1^i, \ldots, x_f = x_f^i\}$—function minimum point $f(x_1, \ldots, x_n)$. Then required concentration will be determined by formulas (5) $- b_1, b_2, \ldots , b_k$, and then mix volume $A$,

$$V = \sum_{j=1}^{l} x_j^n + \sum_{j=l+1}^{n} a_j.$$

Example 4. There are mixes $A_1, A_2, A_3, A_4$ with components $B_1, B_2, B_3$. Volumes of these mixes and concentration of components are respectively equal in them

$$a_1 = 7.6, \quad a_2 = 5.4, \quad a_3 = 4.0, \quad a_4 = 2.4,$$

$$b_1^1 = 0.26, \quad b_1^2 = 0.18, \quad b_1^3 = 0.15, \quad b_1^4 = 0.23,$$

$$b_2^1 = 0.12, \quad b_2^2 = 0.09, \quad b_2^3 = 0.08, \quad b_2^4 = 0.13,$$

$$b_3^1 = 0.25, \quad b_3^2 = 0.17, \quad b_3^3 = 0.17, \quad b_3^4 = 0.24.$$

It is required to make new mix of these mixes $A$ with the relation of concentration of components $b_1 : b_2 : b_3$, the closest to the relation $q_1 : q_2 : q_3 = 5 : 2 : 5$, on condition of full expenditure of mixes $A_3, A_4$.

Decision. Under the set conditions as show the equations (6) to make new mix with the ratio of components $b_1 : b_2 : b_3 = 5 : 2 : 5$ it is impossible.

Let's make function (7) which in this example will take the following form

$$f(x_1, x_2) = 0.01 \left( \frac{x_1 + x_2 - 10.4}{0.25x_1 + 0.17x_2 + 1.256} \right).$$

in the area $\Omega_2$.

Calculations showed that the minimum value of function $f(x_1, x_2)$ in the area $\Omega_1$, and in the area $\Omega_2$ equally $429 \over 4540 = 0.0945$ also is accepted in the point $L$, i.e. at $x_1 = x_1^* = 7.6, \quad x_2 = x_2^* = 2.8$.

This point is answered by concentration of components:
8

\[ b_1 = b_1^* = \frac{227}{1050} \approx 0.2162, \quad b_2 = b_2^* = \frac{449}{4200} \approx 0.1069, \quad b_3 = b_3^* = \frac{227}{1050} \approx 0.2162, \]

and mix volume equal, \( V = 16.8 \).

4. Conclusions
In work, new mix is formed from \( n \) small consignments of mixes or components, but already in a different way, in difference from the work stated above. Some small consignments of mixes or components are spent completely (in statements of tasks it is the last \( n-l \) small batches), and then from each of the remained consignments of small mixes or components (these are the first \( l \) batches) such part of volume that new general mix with the necessary quality characteristics turned out undertakes.

Implementation of these algorithms and their practical use is the technological and economically justified, in terms of the solution of this problem.

These tasks are more difficult, than in the previous research papers of authors [1, 12], as at the analytical decision and for writing of the appropriate computer programs.

The offered approaches and solution algorithms of these tasks are provided for the first time, and their relevance is caused by more and more high requirements imposed by consumers to blend products and goods with its application.

Technique and technology solutions of these tasks can be of interest and to be demanded in the different production industries, for example, at production of premixes for livestock production, at preparation of different food mixes, products and additives, medicines, metal powder materials, in construction industry, in military industry, by production of thixotropic mixes, fertilizers, household chemicals and in many other technology processes.

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