Composition of Modular Telemetry System with Interval Multiset Estimates

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The paper describes combinatorial synthesis approach with interval multiset estimates of system elements for modeling, analysis, design, and improvement of a modular telemetry system. Morphological (modular) system design and improvement are considered as composition of the telemetry system elements (components) configuration. The solving process is based on Hierarchical Morphological Multicriteria Design (HMMD): (i) multicriteria selection of alternatives for system components, (ii) synthesis of the selected alternatives into a resultant combination (while taking into account quality of the alternatives above and their compatibility). Interval multiset estimates are used for assessment of design alternatives for telemetry system elements. Two additional systems problems are examined: (a) improvement of the obtained solutions, (b) aggregation of the obtained solutions into a resultant system configuration. The improvement and aggregation processes are based on multiple choice problem with interval multiset estimates. Numerical examples for an on-board telemetry subsystem illustrate the design and improvement processes.

Keywords: modular system, composition, telemetry, combinatorial optimization, heuristics, multiset

1. Introduction

In recent decades, the significance of various telemetry systems is increased (e.g., [2],[3]). In this article, combinatorial synthesis approach with interval multiset estimates of system elements is suggested for modeling, analysis, design, and improvement of a modular telemetry system. Morphological (modular) system design and improvement are considered as composition of the telemetry system element (components) configuration. Morphological analysis for system design is widely used many years ([1],[5],[20]). Some recent modifications of the approach have been described in ([8],[9],[10],[13],[17]). Here the solving process is based on our new modification of Hierarchical Morphological Multicriteria Design (HMMD) approach (with usage of interval multiset estimates) ([13],[14]): (i) design of a hierarchical structure (tree-like structure) for the designed system, (ii) generation of design alternatives for each leaf node of the system hierarchical model, (iii) assessment of the designed alternatives and their compatibility, (iv) multicriteria selection of alternatives for system components, (v) synthesis of the selected alternatives into a resultant combination (while taking into account ordinal quality of the alternatives above and their compatibility). Interval multiset estimates are used for assessment of design alternatives for telemetry system elements. Two additional systems problems are examined: (a) improvement of the obtained solutions (e.g., [9],[11]), (b) aggregation of the obtained solutions into a resultant system configuration [12]. The improvement and aggregation processes are based on multiple choice problem with interval multiset estimates.

Note, combinatorial modeling and design of a telemetry system has been studied in [15] (HMMD with ordinal estimates) and this work is used as a preliminary one. In this article, the numerical design example is targeted to modeling, design, and improvement of on-board telemetry subsystem while taking into account assessment of system components with interval multiset estimates [14]. The considered example corresponds to real design project. The example involves the following: tree-like structure of the subsystem, design alternatives (DAs) for subsystem parts/components, estimates of DAs

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and their compatibility, Bottom-Up design process, analysis and improvement of the obtained system solutions, and aggregation of the obtained solutions into the resultant one. Assessment of DAs and their compatibility is based on expert judgment.

Fig. 1. Telemetric system

2. Basic Hierarchical Morphological Model

The following hierarchical system model is considered ([9],[12]) (Fig. 2):

![Hierarchical system model](image)

(i) tree-like system model,
(ii) set of leaf nodes as basic system parts/components,
(iii) sets of DAs for each leaf node,
(iv) estimates of DAs (e.g., ordinal priorities, interval multiset estimates); and
(v) estimates of compatibility between DAs (ordinal estimates).

Generally, the hierarchical structure of a telemetry system is the following (Fig. 3):

![Telemetry system structure](image)

3. Combinatorial Synthesis with Interval Multiset Estimates

3.1. Interval Multiset Estimates

Interval multiset estimates have been suggested by M.Sh. Levin in [14]. The approach consists in assignment of elements (1, 2, 3, ...) into an ordinal scale [1, 2, ..., l]. As a result, a multi-set based estimate is obtained, where a basis set involves all levels of the ordinal scale: \( \Omega = \{1, 2, ..., l\} \) (the levels are linear ordered: \( 1 \succ 2 \succ 3 \succ ... \)) and the assessment problem (for each alternative) consists in selection of a multiset over set \( \Omega \) while taking into account two conditions:

1. cardinality of the selected multiset equals a specified number of elements \( \eta = 1, 2, 3, ... \) (i.e.,
multisets of cardinality \( n \) are considered);

2. "configuration" of the multiset is the following: the selected elements of \( \Omega \) cover an interval over scale \([1, l]\) (i.e., "interval multiset estimate").

Thus, an estimate \( e \) for an alternative \( A \) is (scale \([1, l]\), position-based form or position form): 
\[ e(A) = (\eta_1, \ldots, \eta_l) \]
where \( \eta \) corresponds to the number of elements at the level \( \kappa \ (\kappa = 1, l) \),
or \( e(A) = \{1, \ldots, 1, 2, \ldots, 2, 3, \ldots, 3, \ldots, l, \ldots, l\} \). The number of multisets of cardinality \( n \), with elements taken from a finite set of cardinality \( l \), is called the "multiset coefficient" or "multiset number" (\([7, 19]\)): 
\[ \mu^{l, n} = \frac{l!}{(l+n-1)!} \]
This number corresponds to possible estimates (without taking into account interval condition 2). In the case of condition 2, the number of estimates is decreased. Generally, assessment problems based on interval multiset estimates can be denoted as follows: 
\[ P^{k, n} \]
A poset-like scale of interval multiset estimates for assessment problem \( P^{4, 3} \) is presented in Fig. 4. The assessment problem will be used in our applied numerical examples.

In addition, operations over multiset estimates are used \([14]\): integration, vector-like proximity, aggregation, and alignment.

Integration of estimates (mainly, for composite systems) is based on summarization of the estimates by components (i.e., positions). Let us consider \( n \) estimates (position form): 
\[ e^1 = (\eta^1_1, \ldots, \eta^1_l), \ldots, e^n = (\eta^n_1, \ldots, \eta^n_l) \]
Then, the integrated estimate is: 
\[ e^i = (\eta^i_1, \ldots, \eta^i_l), \]
where \( \eta^i_k = \sum_{\kappa=1}^{n} \eta^\kappa_k \ \forall i = 1, l \). In fact, the operation \( \cup \) is used for multiset estimates: 
\[ e^i = e^1 \cup \ldots \cup e^n \]

Further, vector-like proximity is described. Let \( A_1 \) and \( A_2 \) be two alternatives with corresponding interval multiset estimates \( e(A_1), e(A_2) \). Vector-like proximity for the alternatives above is: 
\[ \delta(e(A_1), e(A_2)) = (\delta^-(A_1, A_2), \delta^+(A_1, A_2)) \]
where vector components are: (i) \( \delta^- \) is the number of one-step changes: element of quality \( \kappa + 1 \) into element of quality \( \kappa + 1 \) (this corresponds to "degradation"); (ii) \( \delta^+ \) is the number of one-step changes: element of quality \( \kappa \)
into element of quality \( \kappa + 1 \) (this corresponds to "improvement"). It is assumed: 
\[ |\delta(e(A_1), e(A_2))| = |\delta^-(A_1, A_2)| + |\delta^+(A_1, A_2)| \]

Now let us consider median estimates (aggregation) for the specified set of initial estimates (traditional approach). Let \( E = \{e_1, \ldots, e_n\} \) be the set of specified estimates (or a corresponding set of specified alternatives), let \( \mathcal{D} \) be the set of all possible estimates (or a corresponding set of possible alternatives) \( E \subseteq \mathcal{D} \). Thus, the median estimates ("generalized median" \( M^g \) and "set median" \( M^s \)) are:
\[ M^g = \arg \min_{M \in \mathcal{D}} \sum_{\kappa=1}^{n} |\delta(M, e_\kappa)|; \]
\[ M^s = \]
arg\min_{M \in E} \sum_{k=1}^{n} |\delta(M, e_{i_k})|.

3.2. Morphological Design with Interval Multiset Estimates

A brief description of combinatorial synthesis (HMMD) with ordinal estimates of design alternatives is the following ([9], [10], [13], [14]). An examined composite (modular, decomposable) system consists of components and their interconnection or compatibility (IC). Basic assumptions of HMMD are the following: (a) a tree-like structure of the system; (b) a composite estimate for system quality that integrates components (subsystems, parts) qualities and qualities of IC (compatibility) across subsystems; (c) monotonic criteria for the system and its components; (d) quality of system components and IC are evaluated on the basis of coordinated ordinal scales. The designations are: (1) design alternatives (DAs) for leaf nodes of the model; (2) ordinal compatibility for each pair of DAs for leaf nodes of the model; (3) priori-

The problem is described as follows: (e.g., [4], [6]):

$$\max \ e(S) = M^p = \arg \min_{M \in D} \sum_{i=1}^{m} |\delta(M, e(S_i))|,$$

$$\max w(S),$$

$$\text{s.t.} \ w(S) \geq 1.$$
A special case of multiple choice problem is considered:

(1) multiset estimates of item “utility” $e_{i,j}$, $i \in \{1, ..., i, ..., m\}, j = 1, q_i$ (instead of $c_{ij}$),
(2) an aggregated multiset estimate as the “generalized median” (or “set median”) is used
for the objective function (“maximization”).

The item set is:

$A = \bigcup_{i=1}^{m} A_i$, $A_i = \{(i, 1), (i, 2), ..., (i, q_i)\}$.

Boolean variable $x_{i,j}$ corresponds to selection of the item $(i, j)$.

The solution is a subset of the initial item set: $S = \{(i, j) | x_{i,j} = 1\}$. The problem is:

$$\max e(S) = \max M = \arg \min_{M \in \mathcal{D}} \sum_{(i,j) \in S = \{(i,j)|x_{i,j}=1\}} |\delta(M, e_{i,j})|$$

s.t. $\sum_{i=1}^{m} q_i a_{i,j} x_{i,j} \leq b$, $\sum_{j=1}^{q_i} x_{i,j} = 1$, $x_{i,j} \in \{0, 1\}$.

Here the following algorithms can be used (as for basic multiple choice problem) (e.g.,
[3], [6], [14]): (i) enumerative methods including dynamic programming approach, (ii) heuristics (e.g., greedy algorithms), (iii) approximation schemes (e.g., modifications of dynamic programming approach).

Evidently, this problem is similar to the above-mentioned combinatorial synthesis problem without compatibility of the selected items (objects, alternatives).

4. Example for On-Board Telemetry Subsystem

Here a numerical example for on-board telemetry subsystem is considered from [15]. The initial morphological structure for on-board subsystem is the following (Fig. 5):

1. On-board subsystem $A = D \ast E \ast F$.

1.1. Power supply $D = X \ast Y \ast Z$: 1.1.1. stabilizer $X$: $X_1$ (standard), $X_2$ (transistorized), $X_3$ (high-stability); 1.1.2. main source $Y$: $Y_1$ (Li-ion), $Y_2$ (Cd-Mn), $Y_3$ (Li); 1.1.3. emergency cell $Z$: $Z_1$ (Li-ion), $Z_2$ (Cd-Mn), $Z_3$ (Li).

1.2. Sensor elements $E = I \ast Q \ast G$: 1.2.1. acceleration sensors $I$: $I_1$ (ADXL), $I_2$ (ADIS), $I_3$ (MMA); 1.2.2. position sensors $Q$: $Q_1$ (SS12), $Q_2$ (SS16), $Q_3$ (SS19), $Q_4$ (SS49), $Q_5$ (SS59), $Q_6$ (SS94); 1.2.3. global positioning system (GPS) $G$: $G_1$ (EB), $G_2$ (GT), $G_3$ (LS), $G_4$ (ZX).

1.3. Data processing system $F = H \ast C \ast W$: 1.3.1. data storage unit $H$: $H_1$ (SRAM), $H_2$ (DRAM), $H_3$ (FRAM); 1.3.2. processing unit $C$: $C_1$ (AVR), $C_2$ (ARM), $C_3$ (ADSP), $C_4$ (BM); 1.3.3. data write unit $W$: $W_1$ (built-in ADC), $W_2$ (external ADC I2C), $W_3$ (external ADC SPI), $W_4$ (external ADC 2W), $W_5$ (external ADC UART(I)).

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**Fig. 5. Structure on-board subsystem**
Interval multiset estimates of DAs are shown in Fig. 5 in parentheses (expert judgment). Ordinal estimates of compatibility are presented in Tables 1, 2, 3 (expert judgment, from [15]). Note the initial combinatorial set of design solutions includes 116640 possible system combinations (i.e., \((3 \times 3 \times 3) \times (3 \times 6 \times 4) \times (3 \times 4 \times 5)\)).

4.1. Composite Solutions

The obtained Pareto-efficient composite DAs for composite components are the following:

1. For \(D\): \(D_1 = X_2 \ast Y_2 \ast Z_2, \; N(D_1) = (1; 2, 1, 0, 0)\);
2. For \(E\): \(E_1 = I_3 \ast Q_2 \ast G_4, \; N(E_1) = (3; 3, 0, 0, 0)\);
3. For \(F\): \(F_1 = H_2 \ast C_1 \ast W_2, \; N(F_1) = (1; 2, 1, 0, 0)\);
4. For \(F\): \(F_2 = H_3 \ast C_1 \ast W_2, \; N(F_2) = (3; 1, 2, 0, 0)\).

Fig. 6 illustrates “discrete space” (poset, each component corresponds to Fig. 4) of quality for subsystem \(F\).

For the resultant system, eight obtained combinations of DAs for system parts are considered:

\(A_1 = D_1 \ast E_1 \ast F_1 = (X_2 \ast Y_2 \ast Z_2) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2),\)
\(A_2 = D_1 \ast E_1 \ast F_2 = (X_2 \ast Y_2 \ast Z_2) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_3 \ast C_1 \ast W_2),\)
\(A_3 = D_1 \ast E_2 \ast F_1 = (X_2 \ast Y_2 \ast Z_2) \ast (I_1 \ast Q_1 \ast G_4) \ast (H_2 \ast C_1 \ast W_2),\)
\(A_4 = D_1 \ast E_2 \ast F_2 = (X_2 \ast Y_2 \ast Z_2) \ast (I_1 \ast Q_1 \ast G_4) \ast (H_3 \ast C_1 \ast W_2),\)
\(A_5 = D_2 \ast E_1 \ast F_1 = (X_3 \ast Y_3 \ast Z_3) \ast (I_5 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2),\)
\(A_6 = D_2 \ast E_1 \ast F_2 = (X_3 \ast Y_3 \ast Z_3) \ast (I_5 \ast Q_5 \ast G_4) \ast (H_3 \ast C_1 \ast W_2),\)
\(A_7 = D_2 \ast E_2 \ast F_1 = (X_3 \ast Y_3 \ast Z_3) \ast (I_1 \ast Q_1 \ast G_4) \ast (H_2 \ast C_1 \ast W_2),\) and

\(A_8 = D_2 \ast E_2 \ast F_2 = (X_3 \ast Y_3 \ast Z_3) \ast (I_1 \ast Q_1 \ast G_4) \ast (H_3 \ast C_1 \ast W_2)\).
\[ A_8 = D_2 \ast E_2 \ast F_2 = (X_3 \ast Y_3 \ast Z_3) \ast (I_1 \ast Q_1 \ast G_4) \ast (H_3 \ast C_1 \ast W_2). \]

4.2. Analysis and Improvement

System improvement process can be based on the following [9,11]: (i) improvement of a system component (element), (ii) improvement of compatibility between system components, (iii) change a system structure, e.g., extension of the system by addition of system components/parts. On the other hand, aggregation of several initial system solutions into a resultant one can be considered as the improvement as well [12]. Here system improvement (or reconfiguration) actions by elements and by compatibility are briefly presented. Subsystem \( F = H \ast C \ast W \) is examined as an example (Table 4).

Table 4. Bottlenecks, improvement actions

| Composite DAs | Bottlenecks DA/IC | Improvement actions w/e |
|---------------|-------------------|-------------------------|
| \( F_1 \)     | \( W_2 \)         | \((2,1,0,0) \Rightarrow (3,0,0,0)\) |
| \( F_1 \)     | \( C_1 \)         | \((2,1,0,0) \Rightarrow (3,0,0,0)\) |
| \( F_1 \)     | \( H_2 \)         | \((2,1,0,0) \Rightarrow (3,0,0,0)\) |
| \( F_1 \)     | \( H_2, W_2 \)    | \(1 \Rightarrow 3\) |
| \( F_2 \)     | \( H_3, W_2 \)    | \(3 \Rightarrow 4\) |
| \( F_2 \)     | \( C_1, W_2 \)    | \(3 \Rightarrow 4\) |
| \( F_2 \)     | \( W_2 \)         | \((2,1,0,0) \Rightarrow (3,0,0,0)\) |
| \( F_2 \)     | \( C_1 \)         | \((2,1,0,0) \Rightarrow (3,0,0,0)\) |
| \( F_2 \)     | \( H_3 \)         | \((0,2,1,0) \Rightarrow (3,0,0,0)\) |

The following hypothetical improvement process (by elements) for \( F_2 \) is examined (binary variables \( \{y_{ij}\} \) are used):

1. two versions for element \( W_2 \): \( y_{11} \) (none), \( y_{12} \) \((2,1,0,0) \Rightarrow (3,0,0,0)\);
2. two versions for element \( C_1 \): \( y_{21} \) (none), \( y_{22} \) \((2,1,0,0) \Rightarrow (3,0,0,0)\);
3. three versions for element \( H_3 \): \( y_{31} \) (none), \( y_{32} \) \((0,2,1,0) \Rightarrow (0,3,0,0)\), \( y_{33} \) \((0,2,1,0) \Rightarrow (0,3,0,0)\), \( y_{34} \) \((0,2,1,0) \Rightarrow (2,1,0,0)\), \( y_{35} \) \((0,2,1,0) \Rightarrow (3,0,0,0)\).

Table 5 contains binary variables \( \{y_{ij}\} \), improvement actions and their estimates (illustrative, expert judgment). Thus, the improvement problem is:

\[
\arg \min_{M \in D} \sum_{(i,j) \in S} |\delta(M, e_{ij})|
\]

s.t. \( \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij} y_{ij} \leq b, \sum_{j=1}^{3} y_{ij} = 1, y_{ij} \in \{0,1\}. \)

Table 5. Improvement of \( F_2 \)

| Improvement actions | Multiset estimate \( e_{ij} \) | Cost \((a_{ij})\) |
|---------------------|-------------------------------|-----------------|
| \( y_{11} \) \( (W_2, \text{none}) \) | \((2,1,0,0)\) | 0 |
| \( y_{12} \) \( (W_2 \Rightarrow W_2^1, \text{improvement} 1) \) | \((3,0,0,0)\) | 17 |
| \( y_{21} \) \( (C_1, \text{none}) \) | \((2,1,0,0)\) | 0 |
| \( y_{22} \) \( (C_1 \Rightarrow C_1^1, \text{improvement} 1) \) | \((3,0,0,0)\) | 15 |
| \( y_{31} \) \( (H_3, \text{none}) \) | \((0,2,1,0)\) | 0 |
| \( y_{32} \) \( (H_3 \Rightarrow H_3^2, \text{improvement} 1) \) | \((3,0,0,0)\) | 1 |
| \( y_{33} \) \( (H_3 \Rightarrow H_3^2, \text{improvement} 2) \) | \((1,2,0,0)\) | 7 |
| \( y_{34} \) \( (H_3 \Rightarrow H_3^2, \text{improvement} 3) \) | \((2,1,0,0)\) | 13 |
| \( y_{35} \) \( (H_3 \Rightarrow H_3^3, \text{improvement} 4) \) | \((3,0,0,0)\) | 22 |

Some examples of the improvement solutions are:
1. \( b = 1 \): \( y_{11} = 1 \) \( (W_2, \text{none}) \), \( y_{21} = 1 \) \( (C_1, \text{none}) \), \( y_{32} = 1 \) \( (H_3, \text{improvement} 1) \); \( F_2 \Rightarrow F_2^1 = H_3^1 \ast C_1 \ast W_2, e(F_2^1) = (2,1,0,0) \);
2. \( b = 45 \): \( y_{12} = 1 \) \( (W_2, \text{improvement} 1) \), \( y_{22} = 1 \) \( (C_1, \text{improvement} 1) \), \( y_{34} = 1 \) \( (Z_i, \text{improvement} 3) \); \( F_2 \Rightarrow F_2^2 = H_3^2 \ast C_1 \ast W_2, e(F_2^2) = (3,0,0,0) \).

4.3. Aggregation of Solutions

Aggregation procedures for hierarchical structures are presented in [12]. Here, a simplified approach to aggregation (extension of a “system kernel” based on multiple choice problem) is considered for the obtained eight solutions:

\[ A_1 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2), \]
\[ A_2 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_3 \ast C_1 \ast W_2), \]
\[ A_3 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2), \]
\[ A_4 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2), \]
\[ A_5 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2), \]
\[ A_6 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2), \]
\[ A_7 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2), \]
\[ A_8 = (X_3 \ast Y_3 \ast Z_3) \ast (I_3 \ast Q_5 \ast G_4) \ast (H_2 \ast C_1 \ast W_2). \]
A_6 = (X_3 \cdot Y_3 \cdot Z_3) \cdot (I_3 \cdot Q_5 \cdot G_4) \cdot (H_3 \cdot C_1 \cdot W_2),
A_7 = (X_3 \cdot Y_3 \cdot Z_3) \cdot (I_1 \cdot Q_1 \cdot G_4) \cdot (H_2 \cdot C_1 \cdot W_2),
A_8 = (X_3 \cdot Y_3 \cdot Z_3) \cdot (I_1 \cdot Q_1 \cdot G_4) \cdot (H_3 \cdot C_1 \cdot W_2).

In Fig. 7 and Fig. 8, supersolution and subsolution are depicted.

![Fig. 7. Supersolution](image1)

![Fig. 8. Subsolution](image2)

The obtained subsolution contains three elements (this combination will be considered as “system kernel”). Thus, the aggregation process is considered as multiple choice problem for selection of DAs for subsystem \( \Theta = X \cdot Y \cdot Z \cdot I \cdot Q \cdot H \) (Fig. 9) (without taking into account compatibility). Corresponding binary variables are: \( \{x_{ij}\}, \ i = 1,6, \ j = 1,2 \).

Subsystem: \( \Theta = X \cdot Y \cdot X \cdot I \cdot Q \cdot H \)

![Fig. 9. Selection of DAs for subsystem](image3)

Thus, the problem is:

\[
\arg \min_{M \in \mathcal{D}} \sum_{(i,j) \in S = \{(i,j) | x_{ij} = 1\}} |\delta(M, e_{ij})|,
\]

\[s.t. \sum_{i=1}^{6} \sum_{j=1}^{2} a_{ij} x_{ij} \leq b; \sum_{j=1}^{2} x_{ij} = 1; \ x_{ij} \in \{0,1\}.\]

Estimates are presented in Table 6 (illustrative, expert judgment). Some examples of the resultant solutions are:

(1) \( b = 42: \ x_{12} = 1 (X_3), x_{22} = 1 (Y_3), x_{32} = 1 (Z_3), x_{41} = 1 (I_1), x_{51} = 1 (Q_1), x_{62} = 1 (H_3), \)
\( \Theta_1 = X_3 \cdot Y_3 \cdot Z_3 \cdot I_1 \cdot Q_1 \cdot H_3, c(\Theta_1) = (0,2,1,0); \)

(2) \( b = 53: \ x_{11} = 1 (X_2), x_{21} = 1 (Y_2), x_{32} = 1 (Z_3), x_{41} = 1 (I_1), x_{51} = 1 (Q_1), x_{62} = 1 (H_3), \)
\( \Theta_2 = X_2 \cdot Y_2 \cdot Z_3 \cdot I_1 \cdot Q_1 \cdot H_3, c(\Theta_2) = (1,2,0,0); \)

(3) \( b = 87: \ x_{11} = 1 (X_2), x_{21} = 1 (Y_2), x_{31} = 1 (Z_2), x_{42} = 1 (I_3), x_{52} = 1 (Q_5), x_{61} = 1 (H_2), \)
\( \Theta_3 = X_2 \cdot Y_2 \cdot Z_2 \cdot I_3 \cdot Q_5 \cdot H_2, c(\Theta_3) = (2,1,0,0). \)

Table 6. Estimates for aggregation

| Selection of DA | Multiset estimate \( e_{ij} \) | Cost \( (a_{ij}) \) |
|-----------------|-----------------------------|--------------------|
| \( x_{11} (X_2) \) | (2, 1, 0, 0) | 11 |
| \( x_{12} (X_3) \) | (0, 2, 1, 0) | 4 |
| \( x_{21} (Y_2) \) | (2, 1, 0, 0) | 10 |
| \( x_{22} (Y_3) \) | (0, 1, 1, 1) | 2 |
| \( x_{31} (Z_2) \) | (2, 1, 0, 0) | 12 |
| \( x_{32} (Z_3) \) | (0, 2, 1, 0) | 6 |
| \( x_{41} (I_1) \) | (1, 2, 0, 0) | 7 |
| \( x_{42} (I_3) \) | (3, 0, 0, 0) | 20 |
| \( x_{51} (Q_1) \) | (2, 1, 0, 0) | 14 |
| \( x_{52} (Q_5) \) | (3, 0, 0, 0) | 21 |
| \( x_{61} (H_2) \) | (2, 1, 0, 0) | 13 |
| \( x_{62} (H_3) \) | (0, 2, 1, 0) | 5 |

5. Conclusion

The paper describes a hierarchical approach to composition of modular telemetry systems. Hierarchical morphological multicriteria design and multiple choice knapsack problem with interval multiset estimates are used for combinatorial synthesis and improvement of the telemetry system. Evidently, usage of more complicated assessment problems (e.g., \( P^6,5 \)) will lead to more exact and realistic solving processes.

In the future, it may be prospective to consider the following research directions: 1. examination of design and improvement/adaptation problems for telemetry systems as real-time reconfiguration; 2. examination of a distributed telemetry system that is based on a set of vehicles and/or a set of ground points; 3. examination of various applications in engineering and management; 4. usage of interval multiset estimates for compatibility between design alternatives (in this case
the combinatorial synthesis problem may be more easy); 5. consideration of AI techniques (e.g., [18]); and 6. usage of the described approach in engineering/management/CS education.

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