A method for the modelling of integrated network TV production facilities

A. Deliysky

Balgarska Nacionalna Televizija

Having carried out a comprehensive analysis of television production systems from a data-processing viewpoint [1], the Author describes a functional model of a base network platform that has been developed by means of the theoretical instruments of the Generalized Nets. A method for the modelling of typical production operations – by removing unwanted facilities from the base network platform model – is also briefly described.

The proposed model clarifies the interaction between the author-editor and creative realization activities. It also shows what kinds of data are used and generated by different types of data-processing modules – looking at television signal-processing and transport from both a network / data-file aspect and a datastream aspect. The model provides connectivity to both these domains.

The software realization of the model may be used as a valuable practical tool for optimizing project-planning decisions.

1. Introduction

In order to build an efficient, integrated, network production facility, the data which characterizes TV products (i.e. the programme material) should be carefully analyzed, both as regards their functional purpose and the method of their processing.

A TV product naturally bears the features of a virtual object. It is “born” with the creating of the original data that specifies it. It is then “developed” and has a definite “life duration”.

TV products can conditionally be subdivided into two types – *primary* and *derivative*.

Primary TV products are those whose *Essence* (Video, Audio and Data) and *Vital Metadata* (absolutely necessary for subsequent processing of the Essence [2]) are created for the first time. Derivative TV products are those which are created from primary TV products by means of updating, modifications and / or combining different products.

Two different methodologies are used to create primary TV products:

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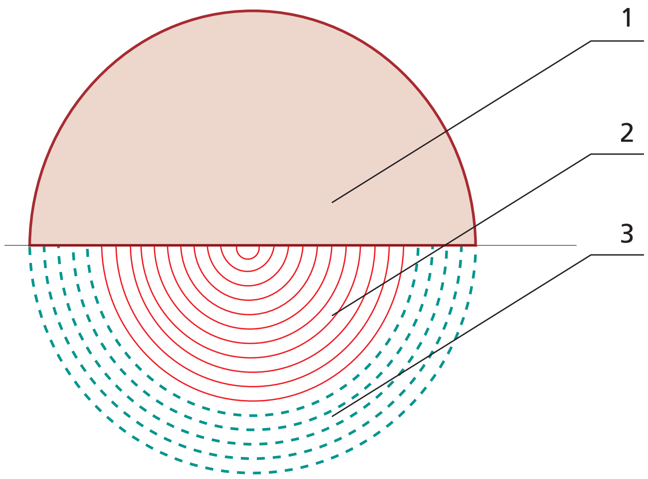
a) Methodology I

First, the X dataset arises. This consists of the Essence data along with that obligatory part of the Vital Metadata which includes the basic Essential [1], Parametric, Geospatial and Relational metadata, without which it is impossible to make use of the Essence. Later on, the Y dataset is generated which includes the rest of the Vital Metadata, of the type UMID Status, Descriptive, Access, Composition, etc. During the period of subsequent processing and depending on the concrete application involved, customer-defined, specialized-reference, script and other metadata can be created at different times. This metadata constitutes the Z dataset.

b) Methodology II

Firstly, the creative project and the script are worked out, normally in conjunction with the use of reference metadata, including that of TV products in their reference metadata aspect. Later on, based on the script, the X dataset is created and after that, similar to methodology I, the Y and Z datasets are created.

It can be summarized that, depending on the character and purpose of the TV product data, they can arise at different times and have different durations of existence. A TV product arises at a definite location, it goes through definite processing modules within the production chain until it reaches its destination(s), where the physical environment for definite data types can be different. Thus any TV product has its own "biography", both as regards its functional-logical aspects and its physical aspects.



1 = Essence data

2 = Tightly-coupled metadata

3 = Loosely-coupled metadata

Figure 1
The three basic components of a TV product, from a data-processing viewpoint.

From its physical manner of transfer and processing, the TV product can be broken down conditionally into three data classes (see *Fig. 1*):

- Essence data;
- tightly-coupled metadata, transmitted and stored with the Essence data without compromise [2];
- loosely-coupled metadata, which may be transmitted and stored separately [2].

Similar to an "iceberg" structure, class 1 data are the representative ("visible") part of the TV product. Its "invisible" part includes class 2 and class 3 data which are logically layered into levels in accordance with the priorities of the TV product processing. (In *Fig. 1*, class 2 data levels are indicated by red lines and class 3 data levels by green dashed lines.) Thus, the location in the "iceberg" structure of any data type should be defined every time, before both processing and transfer.

1. UMID (Unique Material Identifier) Prefix and Core, Video/Audio format, number of Audio channels, etc.

2. Modelling the data processing of TV products

At the lowest hierarchical level of the man-machine system of TV production control, two groups of metadata are generated and processed:

1) Metadata which are the product of the author-editor activity; for example, creative projects, scripts, language translations, descriptive metadata, playout schedules of editorial products etc., and production management / report data. They have a relatively higher degree of freedom in time and place of processing, in relation to the representative part (the Essence) of the TV product, and they fall into the class of "loosely-coupled metadata". For the processing of this data group, relatively modest resources of computing capacity are required.

2) Metadata which are the product of creative realization activities, and which are closely related to Essence data processing. Along with the "tightly-coupled metadata", they can also include other types of Vital metadata. The processing of these metadata types should be effected (as regards time and place) together with the Essence data processing, which requires considerably more powerful computation resources than those of group 1.

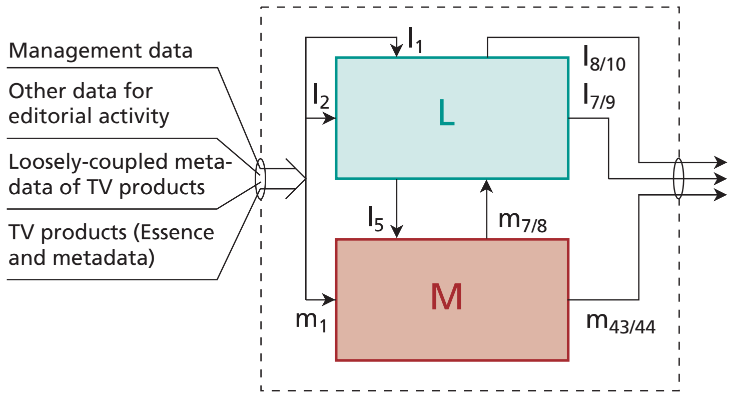
With the present level of data-processing techniques, the different requirements for the two aforementioned data groups demand a differentiation of the data processing into two autonomous interrelated subsystems "L" and "M" (as shown in *Fig. 2*) for the processing of group 1 and group 2 data respectively [3].

This processing principle is valid for the production system as a whole and, to a certain extent, for the basic subsystems that make up the complete production system [3][4].

Therefore, a model of the entire production system – by means of which, and in accordance with the above principle, all typical data-processing functions at the level of the system application layer [5] are presented – should be considered as a functional model of the data-processing base network platform.

Thus:

➩ each basic production subsystem can be described by means of this model, as a subset of the base platform.



Key:

- l_1 = Management data
- l_2 = External data including loosely-coupled metadata of TV products, which are necessary for editorial activity.
- m_1 = External TV products (programme material) data, which are necessary for TV production activity.
- l_5 = Metadata (including management data) for TV production.
- $m_{7/8}$ = TV products data, which are neccessary for editorial activity and for production report.
- $l_{8/10}$ = Production report data, for export
- $l_{7/9}$ = Editiorial data, including loosely-coupled metadata of TV products, for export.
- $m_{43/44}$ = TV products data, for export.

Figure 2
The two inter-related subsystems "L" and "M" for the processing of group 1 and group 2 data respectively.

➩ the functional model of any integrated network production facility can be structured as a composition of adequately-linked subsystems, modelled in a unified manner.

3. A functional model of the base network platform [6]

The functional model now described (see *Fig. 3)* was developed on the basis of the theoretical instruments of Generalized Nets [7][8][9] (see the Appendix). This model interprets the most typical data-processing functions at the level of the system application layer, in line with the conclusions and recommendations of the EBU / SMPTE *Task Force for Harmonized Standards for the Exchange of Programme Material as Bitstreams* [2][5][10][11][12].

As the model is based on the data-processing principle presented in *Fig. 2*, a definite similarity exists with the indications in *Fig. 2*; namely, the places that relate to subsystem "L" processes are denominated by "l", and the places that relate to subsystem "M" processes are denominated by "m".

Subsystem "L" includes the transitions $Z_{0.2}$, $Z_{0.3}$, $Z_{0.4}$ and $Z_{0.5}$, and subsystem "M" includes the transitions Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7, Z_8, Z_9 and Z_{10}. Transition $Z_{0.1}$ is common for the input data to both subsystems, and transitions $Z_{0.6}$ and $Z_{0.7}$ are common for the output data from both subsystems.

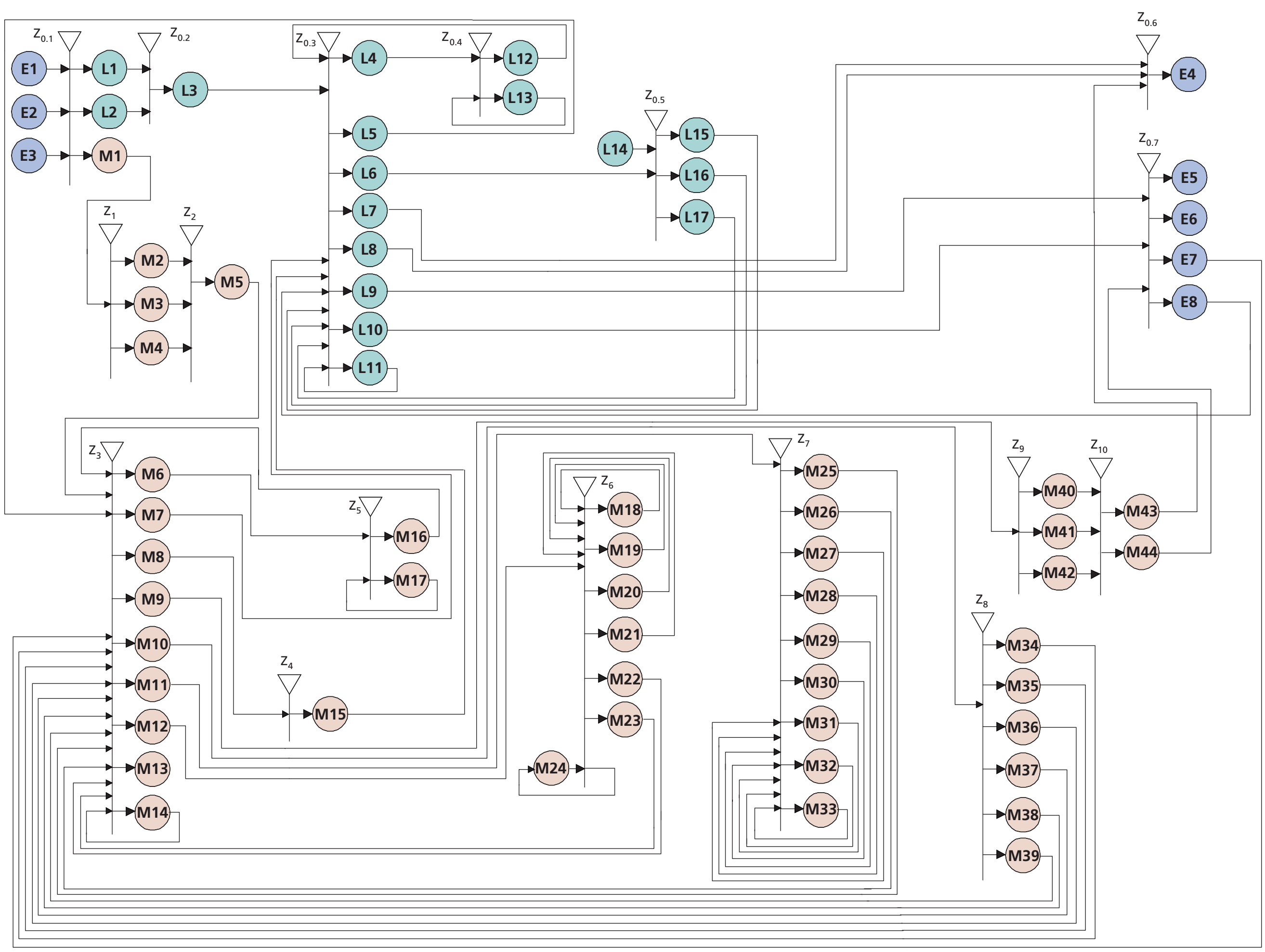


Figure 3
The data-processing base network model, developed on the basis of the theoretical instruments of Generalized Nets.

With reference to *Fig. 3*, the tokens enter the Generalized Net (GN) according to their initial characteristics as follows:

- "*Data, which are received in SDI Streaming format*" into place E_1;
- "*Data, which are received in Wrapper Streaming format*" into place E_2;
- "*Data, which are received in Wrapper storage format*" into place E_3.

The Transition $Z_{0.1}$ (see the green panel to the right) interprets the activities "*Identification of the Wrapper format, of the objects, of their data structure, of the data type, and distribution of the objects in accordance with the activity, for which they are necessary*".

The tokens obtain the characteristics as follows:

- "*Management data*" in place l_1;
- "*External data for editorial activity, including loosely-coupled metadata of TV products*" in place l_2;
- "*External TV products data for TV products production activity*" in place m_1.

$Z_{0.1} = < \{e_1, e_2, e_3\}, \{l_1, l_2, m_1\},$

	l_1	l_2	m_1
e_1	false	false	true
e_2	We_2l_1	We_2l_2	We_2m_1
e_3	We_3l_1	We_3l_2	We_3m_1

$>,$

where: $We_2l_1 = We_3l_1 =$ "*The data are coming from a higher hierarchical control level*"

$We_2l_2 = We_3l_2 =$ "*The data are necessary for editorial activity*"

$We_2m_1 = We_3m_1 =$ "*The data are necessary for TV products production activity*"

The transition $Z_{0.2}$ interprets the activities "*Entering additional metadata into the object, and organization of its data in a Wrapper storage structure, suitable for editorial processing*".

The tokens obtain the characteristics as follows:

- "*Object-oriented data, organized in a Wrapper storage structure, suitable for editorial processing*" (where the Content is intended to be randomly accessed, searched, updated, modified and browsed) in place l_3.

$Z_{0.2} = < \{l_1, l_2\}, \{l_3\},$

	l_3
l_1	true
l_2	true

$>,$

The Transition $Z_{0.3}$ (next page) interprets the activities "*Recording and distribution of the data subject to editorial control and processing*".

The tokens obtain the characteristics as follows:

- "*Data for storage in the editorial library*" in place l_4;
- "*Object-oriented metadata for TV products production*" (scripts, language translations, descriptive metadata, management data, etc.) in place l_5;
- "*Object-oriented data for editorial and production management / report activities*" in place l_6;
- "*Editorial data, including loosely-coupled metadata of TV products for export by File Transfer*" in place l_7;
- "*Production report data for export by File Transfer*" in place l_8;

$$Z_{0.3} = < \{l_{12}, l_3, m_7, m_{15}, e_8, l_{15}, l_{16}, l_{17}, l_{11}\}, \{l_4, l_5, l_6, l_7, l_8, l_9, l_{10}, l_{11}\},$$

	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}
l_{12}	false	true	Wl_{12},l_6	Wl_{12},l_7	Wl_{12},l_8	Wl_{12},l_9	Wl_{12},l_{10}	Wl_{12},l_{11}
l_3	Wl_3, l_4	false	Wl_3,l_6	Wl_3,l_7	Wl_3,l_8	Wl_3,l_9	Wl_3,l_{10}	Wl_3,l_{11}
m_7	Wm_7,l_4	false	Wm_7,l_6	Wm_7,l_7	Wm_7,l_8	Wm_7,l_9	Wm_7,l_{10}	Wm_7,l_{11}
m_{15}	$Wm_{15}l_4$	false	true	false	false	false	false	Wm_{15},l_{11}
e_8	We_8,l_4	true	false	false	false	true	false	We_8,l_{11}
l_{15}	Wl_{15},l_4	true	false	Wl_{15},l_7	false	Wl_{15},l_9	false	Wl_{15},l_{11}
l_{16}	Wl_{16},l_4	true	false	Wl_{16},l_7	false	Wl_{16},l_9	false	Wl_{16},l_{11}
l_{17}	Wl_{17},l_4	true	false	false	Wl_{17},l_8	false	Wl_{17},l_{10}	Wl_{17},l_{11}
l_{11}	Wl_{11},l_4	true	Wl_{11},l_6	Wl_{11},l_7	Wl_{11},l_8	Wl_{11},l_9	Wl_{11},l_{10}	true

$>,$

where: $W\,l_{12},l_7 = W\,l_3,l_7 = W\,m_7,l_7 = W\,l_{15},l_7 = W\,l_{16},l_7 = W\,l_{11},l_7 = W\,l_{12},l_8 = W\,l_3,l_8 = W\,m_7,l_8 = W\,l_{17},l_8 = W\,l_{11},l_8$ = "*The data are necessary for sending by File Transfer*"

$W\,l_{12},l_9 = W\,l_3,l_9 = W\,m_7,l_9 = W\,l_{15},l_9 = W\,l_{16},l_9 = W\,l_{11},l_9 = W\,l_{12},l_{10} = W\,l_3,l_{10} = W\,m_7,l_{10} = W\,l_{17},l_{10} = W\,l_{11},l_{10}$ = "*The data are necessary for sending by Streaming*"

$W\,l_3,l_4 = W\,m_7,l_4 = W\,m_{15}l_4 = W\,e_8,l_4 = W\,l_{15},l_4 = W\,l_{16},l_4 = W\,l_{17},l_4 = W\,l_{11},l_4$ = "*The data need storage in the editorial library*"

$W\,l_{12},l_6 = W\,l_3,l_6 = W\,m_7,l_6 = W\,l_{11},l_6$ = "*The data are necessary for the editorial and production management / report activities*"

$W\,l_{12},l_{11} = W\,l_3,l_{11} = W\,m_7,l_{11} = W\,m_{15},l_{11} = W\,e_8,l_{11} = W\,l_{15},l_{11} = W\,l_{16},l_{11} = W\,l_{17},l_{11}$ = "*The data need short-term storage*"

- "*Editorial data, including loosely-coupled metadata of TV products for export by Streaming*" in place l_9;
- "*Production report data for export by Streaming*" in place l_{10}.

The unique token (which circulates only in place l_{11}) obtains as a characteristic the characteristics of the tokens from places l_{12}, l_3, m_7, m_{15}, e_8, l_{15}, l_{16} and l_{17}, which interprets the short-term storage process of the incoming information.

The transition $Z_{0.4}$ interprets the activities "*Storage and use of editorial products library data*".

The tokens obtain the characteristics as follows:

- "*Data from the editorial library for operative use*" in place l_{12}.

They do not obtain any characteristics in place l_{13}, which interprets the library process of editorial products.

$$Z_{0.4} = < \{l_4, l_{13}\}, \{l_{12}, l_{13}\},$$

	l_{12}	l_{13}
l_4	false	true
l_{13}	$W\,l_{13},l_{12}$	true

$>,$

where: $W\,l_{13},l_{12}$ = "*It is necessary to use editorial products library data*"

The tokens enter the GN with initial characteristics "*Personal information for ensuring editorial activity*".

The transition $Z_{0.5}$ interprets the activities "*Creation and processing of data for TV products control and production*".

$Z_{0.5} = < \{l_{14}, l_6\}, \{l_{15}, l_{16}, l_{17}\},$

	l_{15}	l_{16}	l_{17}	
l_{14}	true	true	false	>,
l_6	true	true	true	

The tokens obtain the characteristics as follows:

- "*Editorial products (creative projects, scripts, language translation, etc.)*" in place l_{15};
- "*Descriptive metadata*" in place l_{16};
- "*Production management / report data*" in place l_{17}.

The transition Z_1 interprets the activities "*Adapting the technical characteristics of Video, Audio and Data Essence signals to the selected studio processing format*".

$Z_1 = < \{m_1\}, \{m_2, m_3, m_4\},$

	m_2	m_3	m_4	
m_1	true	true	true	>,

The tokens obtain the characteristics as follows:

- "*TV product Video and Data Essence with technical characteristics of the required signal format for studio processing*" in place m_2;
- "*TV product Audio Essence with technical characteristics of the required signal format for studio processing*" in place m_3;
- "*TV product metadata*" in place m_4.

The transition Z_2 interprets the activities "*Entering additional metadata into the TV product, and organization of its data in a Wrapper storage structure suitable for studio processing*".

$Z_2 = < \{m_2, m_3, m_4\},\{m_5\},$

	m_5	
m_2	true	
m_3	true	>,
m_4	true	

The tokens obtain the characteristics as follows:

- "*External TV products data, which are organized in convenient Wrapper storage structure for studio processing (randomly accessed, searched, browsed, updated, modified)*" in place m_5.

The transition Z_3 (see the following page) interprets the activities "*Recording and distribution of data representing and characterizing the TV products*".

The tokens obtain the characteristics as follows:

- "*Data for storage in the TV products library*" in place m_6;
- "*TV products metadata, which are necessary for the editorial activity and for the production report*" in place m_7;

$Z_3 = < \{ m_{16}, m_5, l_5, e_7, m_{34}, m_{35}, m_{36}, m_{37}, m_{38}, m_{39}, m_{25}, m_{26}, m_{22}, m_{23}, m_{14}\},$
$\{m_6, m_7, m_8, m_9, m_{10}, m_{11}, m_{12}, m_{13}, m_{14}\},$

	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	
m_{16}	false	true	true	true	true	true	true	true	$W\ m_{16},m_{14}$	
m_5	$W\ m_5,m_6$	true	true	true	true	true	true	false	$W\ m_5,m_{14}$	
l_5	$W\ l_5,m_6$	false	false	false	true	true	true	true	$W\ l_5,m_{14}$	
e_7	$W\ e_7,m_6$	false	false	true	false	false	false	false	$W\ e_7,m_{14}$	
m_{34}	$W\ m_{34},m_6$	true	true	true	true	false	false	true	$W\ m_{34},m_{14}$	
m_{35}	$W\ m_{35},m_6$	true	true	true	true	false	false	false	$W\ m_{35},m_{14}$	
m_{36}	$W\ m_{36},m_6$	true	true	true	true	false	false	false	$W\ m_{36},m_{14}$	
m_{37}	$W\ m_{37},m_6$	true	true	true	true	false	false	false	$W\ m_{37},m_{14}$	>,
m_{38}	$W\ m_{38},m_6$	true	true	true	true	false	false	false	$W\ m_{38},m_{14}$	
m_{39}	$W\ m_{39},m_6$	true	true	true	true	false	false	false	$W\ m_{39},m_{14}$	
m_{25}	$W\ m_{25},m_6$	true	true	true	true	false	false	false	$W\ m_{25},m_{14}$	
m_{26}	$W\ m_{26},m_6$	true	true	true	true	false	false	false	$W\ m_{26},m_{14}$	
m_{22}	$W\ m_{22},m_6$	true	true	true	true	true	false	false	$W\ m_{22},m_{14}$	
m_{23}	$W\ m_{23},m_6$	true	true	true	true	true	false	false	$W\ m_{23},m_{14}$	
m_{14}	$W\ m_{14},m_6$	true	true	true	true	true	true	true	true	

where: $W\ m_5,m_6 = W\ l_5,m_6 = W\ e_7,m_6 = W\ m_{34},m_6 = W\ m_{35},m_6 = W\ m_{36},m_6 = W\ m_{37},m_6 = W\ m_{38},m_6 = W\ m_{39},m_6 = W\ m_{25},m_6 = W\ m_{26},m_6 = W m_{22},m_6 = W m_{23},m_6 = W\ m_{14},m_6 =$ "*The data need storage in the TV products library*";

$W\ m_{16},m_{14} = W\ m_5, m_{14} = W\ l_5,m_{14} = W\ e_7,m_{14} = W\ m_{34},m_{14} = W\ m_{35},m_{14} = W\ m_{36},m_{14} = W\ m_{37},m_{14} = W\ m_{38},m_{14} = W\ m_{39},m_{14} = W\ m_{25},m_{14} = W\ m_{26},m_{14} = W\ m_{22},m_{14} = W\ m_{23},m_{14} =$ "*The data need short-term storage*".

- "*TV products Essence (Video, Audio, Data Essence), which are necessary for the editorial activity*" in place m_8;
- "*TV products data for export*" in place m_9;
- "*Data for TV products composition*" in place m_{10};
- "*Data for TV products processing*" in place m_{11};
- "*Data for TV products synthezis*" in place m_{12};
- "*Titles for the speakers*" in place m_{13}.

The unique token (which circulates only in place l_{14}) obtains as a characteristic the characteristics of the tokens from places m_{16}, m_5, l_5, e_7, m_{34}, m_{35}, m_{36}, m_{37}, m_{38}, m_{39}, m_{25}, m_{26}, m_{22} and m_{23}, which interprets the short-term storage process of the incoming information.

The transition Z_4 interprets the activities "*Minimizing the volume of Video, Audio, Data Essence in order to use them as monitoring data*".

$Z_4 = < \{ m_8 \},\{m_{15} \},$

	m_{15}	
m_8	true	>,

The tokens obtain the characteristics as follows:

- "*Compressed TV products Essence data, which are used as monitoring data for editorial activity*" in place m_{15}.

The transition Z_5 interprets the activities "*Storage and use of TV products library data*".

The tokens obtain the characteristics as follows:

- "*Data from the TV product library for operative use*" in place m_{16}.

They do not obtain any characteristics in place m_{17}, which interprets the library processes of TV products.

$Z_5 = < \{ m_6 , m_{17} \},\{m_{16} ,m_{17} \},$

	m_{16}	m_{17}	
m_6	false	true	>,
m_{17}	$W\ m_{17},m_{16}$	true	

where: $W\ m_{17},m_{16}$ = "*It is necessary to use TV products library data*"

The transition Z_6 (see the following page) interprets the activities "*Synthesis of TV objects*".

The tokens obtain the characteristics as follows:

- "*Modelled 2D Video objects*" in place m_{18};
- "*Modelled 3D Video objects*" in place m_{19};
- "*Special Video and Audio effects*" in place m_{20};
- "*Modelled Audio objects*" in place m_{21};
- "*Essence data of the generated TV objects*" in place m_{22};
- "*Metadata (Essential, Parametric, Geospatial, Relational, etc.) of the generated TV objects*" in place m_{23}.

The unique token (which circulates only in place m_{24}) obtains as a characteristic the characteristics of definite tokens from places m_{18}, m_{19}, m_{20}, m_{21} and m_{12}, which interprets the work of a library of initial products for TV objects synthezis (graphical primitives, primary and derivative video / audio objects).

The transition Z_7 (see the following page) interprets the activities "*TV products processing*".

The tokens obtain the characteristics as follows:

- "*Essence data of the processed TV objects*" in place m_{25};
- "*Metadata (Essential, Parametric, Relational, etc.) of the processed TV objects*" in place m_{26};
- "*Textured Video objects*" in place m_{27};
- "*Geometrically deformed Video objects*" in place m_{28};
- "*Animated Video objects (including light sources, morphing, etc.)*" in place m_{29};
- "*Rendered Video objects*" in place m_{30};
- "*Regenerated TV objects*" in place m_{31};
- "*Processed Audio objects*" in place m_{32}.

The unique token (which circulates only in place m_{33}) obtains as a characteristic the characteristics of definite tokens from places m_{11}, m_{27}, m_{28}, m_{29}, m_{30}, m_{31} and m_{32}, which interprets the

$$Z_6 = < \{ m_{18}, m_{19}, m_{20}, m_{21}, m_{12}, m_{24} \}, \{ m_{18}, m_{19}, m_{20}, m_{21}, m_{22}, m_{23}, m_{24} \},$$

	m_{18}	m_{19}	m_{20}	m_{21}	m_{22}	m_{23}	m_{24}
m_{18}	false	false	false	false	true	true	$W\ m_{18},m_{24}$
m_{19}	false	false	false	false	true	true	$W\ m_{19},m_{24}$
m_{20}	false	false	false	false	true	true	$W\ m_{20},m_{24}$
m_{21}	false	false	false	false	true	true	$W\ m_{21},m_{24}$
m_{12}	false	false	false	false	false	false	true
m_{24}	true	true	true	true	true	true	true

$>,$

where: $W\ m_{18},m_{24} = W\ m_{19},m_{24} = W\ m_{20},m_{24} = W\ m_{21},m_{24}$ = *"The generated TV product should be stored in the library of initial products for TV objects synthesis"*.

$$Z_7 = < \{ m_{11}, m_{27}, m_{28}, m_{29}, m_{30}, m_{31}, m_{32}, m_{33} \},$$
$$\{ m_{25}, m_{26}, m_{27}, m_{28}, m_{29}, m_{30}, m_{31}, m_{32}, m_{33} \},$$

	m_{25}	m_{26}	m_{27}	m_{28}	m_{29}	m_{30}	m_{31}	m_{32}	m_{33}
m_{11}	false	false	Wm_{11},m_{27}	Wm_{11},m_{28}	Wm_{11},m_{29}	Wm_{11},m_{30}	Wm_{11},m_{31}	Wm_{11},m_{32}	Wm_{11},m_{33}
m_{27}	Wm_{27},m_{25}	Wm_{27},m_{26}	false	Wm_{27},m_{28}	Wm_{27},m_{29}	Wm_{27},m_{30}	Wm_{27},m_{31}	Wm_{27},m_{32}	Wm_{27},m_{33}
m_{28}	Wm_{28},m_{25}	Wm_{28},m_{26}	Wm_{28},m_{27}	false	Wm_{28},m_{29}	Wm_{28},m_{30}	Wm_{28},m_{31}	Wm_{28},m_{32}	Wm_{28},m_{33}
m_{29}	Wm_{29},m_{25}	Wm_{29},m_{26}	Wm_{29},m_{27}	Wm_{29},m_{28}	false	Wm_{29},m_{30}	Wm_{29},m_{31}	Wm_{29},m_{32}	Wm_{29},m_{33}
m_{30}	Wm_{30},m_{25}	Wm_{30},m_{26}	Wm_{30},m_{27}	Wm_{30},m_{28}	Wm_{30},m_{29}	false	Wm_{30},m_{31}	Wm_{30},m_{32}	Wm_{30},m_{33}
m_{31}	Wm_{31},m_{25}	Wm_{31},m_{26}	Wm_{31},m_{27}	Wm_{31},m_{28}	Wm_{31},m_{29}	Wm_{31},m_{30}	false	Wm_{31},m_{32}	Wm_{31},m_{33}
m_{32}	Wm_{32},m_{25}	Wm_{32},m_{26}	Wm_{32},m_{27}	Wm_{32},m_{28}	Wm_{32},m_{29}	Wm_{32},m_{30}	Wm_{32},m_{31}	false	Wm_{32},m_{33}
m_{33}	Wm_{33},m_{25}	Wm_{33},m_{26}	Wm_{33},m_{27}	Wm_{33},m_{28}	Wm_{33},m_{29}	Wm_{33},m_{30}	Wm_{33},m_{31}	Wm_{33},m_{32}	true

$>,$

where: $W^{27} = W\ m_{11},m_{27} = W\ m_{28},m_{27} = W\ m_{29},m_{27} = W\ m_{30},m_{27} = W\ m_{31},m_{27} = W\ m_{32},m_{27} = W\ m_{33},m_{27}$ = *"The video object needs texturing"*

$W^{28} = W\ m_{11},m_{28} = W\ m_{27},m_{28} = W\ m_{29},m_{28} = W\ m_{30},m_{28} = W\ m_{31},m_{28} = W\ m_{32},m_{28} = W\ m_{33},m_{28}$ = *"The video object needs geometrical deformation"*

$W^{29} = W\ m_{11},m_{29} = W\ m_{27},m_{29} = W\ m_{28},m_{29} = W\ m_{30},m_{29} = W\ m_{31},m_{29} = W\ m_{32},m_{29} = W\ m_{33},m_{29}$ = *"The video object needs animation"*.

$W^{30} = W\ m_{11},m_{30} = W\ m_{27},m_{30} = W\ m_{28},m_{30} = W\ m_{29},m_{30} = Wm_{31},m_{30} = W\ m_{32},m_{30} = W\ m_{33},m_{30}$ = *"The video object needs rendering"*.

$W^{31} = W\ m_{11},m_{31} = W\ m_{27},m_{31} = W\ m_{28},m_{31} = W\ m_{29},m_{31} = W\ m_{30},m\ _{31} = W\ m_{32},m_{31} = W\ m_{33},m_{31}$ = *"The TV object needs re-generation"*.

$W^{32} = W\ m_{11},m_{32} = W\ m_{27},m_{32} = W\ m_{28},m_{32} = W\ m_{29},m_{32} = W\ m_{30},m_{32} = W\ m_{31},m_{32} = W\ m_{33},m_{32}$ = *"The Audio object needs processing"*.

$W^{33} = W\ m_{11},m_{33} = W\ m_{27},m_{33} = W\ m_{28},m_{33} = W\ m_{29},m_{33} = W\ m_{30},m_{33} = W\ m_{31},m_{33} = W\ m_{32},m_{33}$ = *"The TV object needs storage"*.

$W\ m_{27},m_{25} = W\ m_{27},m_{26} = (-W^{28})\Lambda\ (-W^{29})\Lambda\ (-W^{30})\Lambda\ (-W^{31})\Lambda\ (-W^{32})\Lambda\ (-W^{33})$

$W\ m_{28},m_{25} = W\ m_{28},m_{26} = (-W^{27})\Lambda\ (-W^{29})\Lambda\ (-W^{30})\Lambda\ (-W^{31})\Lambda\ (-W^{32})\Lambda\ (-W^{33})$

$W\ m_{29},m_{25} = W\ m_{29},m_{26} = (-W^{27})\Lambda\ (-W^{28})\Lambda\ (-W^{30})\Lambda\ (-W^{31})\Lambda\ (-W^{32})\Lambda\ (-W^{33})$

$W\ m_{30},m_{25} = W\ m_{30},m_{26} = (-W^{27})\Lambda\ (-W^{28})\Lambda\ (-W^{29})\Lambda\ (-W^{31})\Lambda\ (-W^{32})\Lambda\ (-W^{33})$

$W\ m_{31},m_{25} = W\ m_{31},m_{26} = (-W^{27})\Lambda\ (-W^{28})\Lambda\ (-W^{29})\Lambda\ (-W^{30})\Lambda\ (-W^{32})\Lambda\ (-W^{33})$

$W\ m_{32},m_{25} = W\ m_{32},m_{26} = (-W^{27})\Lambda\ (-W^{28})\Lambda\ (-W^{29})\Lambda\ (-W^{30})\Lambda\ (-W^{31})\Lambda\ (-W^{33})$

$W\ m_{33},m_{25} = W\ m_{33},m_{26} = (-W^{27})\Lambda\ (-W^{28})\Lambda\ (-W^{29})\Lambda\ (-W^{30})\Lambda\ (-W^{31})\Lambda\ (-W^{32})$

work of a library of processing tools, such as textures, classical animation effects etc., and the short-term storage of processed TV objects.

The transition Z_8 interprets the activities "*Composing of TV products through editing of two or more TV products*".

$Z_8 = < \{m_{10}\}, \{m_{34}, m_{35}, m_{36}, m_{37}, m_{38}, m_{39}\},$

	m_{34}	m_{35}	m_{36}	m_{37}	m_{38}	m_{39}	
m_{10}	true	true	true	true	true	true	>,

The tokens obtain the characteristics as follows:

- "*Subtitles (Content + characters)*" in place m_{34};
- "*Audio composition schedules*" in place m_{35};
- "*Video composition schedules*" in place m_{36};
- "*Control metadata for the interframe transitions*" in place m_{37};
- "*Control metadata for "key" (including "Chromakey") intraframe composing*" in place m_{38};
- "*Other metadata (Essential, Parametric, Relational, including data for synchronization between Video, Audio, Subtitles on the basis of time code, etc.)*" in place m_{39}.

The transition Z_9 interprets the activities "*Adapting the technical characteristics of Video, Audio and Data Essence signals to the required transport format*".

$Z_9 = < \{m_9\}, \{m_{40}, m_{41}, m_{42}\},$

	m_{40}	m_{41}	m_{42}	
m_9	true	true	true	>,

The tokens obtain the characteristics as follows:

- "*TV product Video and Data Essence with technical characteristics of the required transport signal format*" in place m_{40};
- "*TV product Audio Essence with technical characteristics of the required transport signal format*" in place m_{41};
- "*TV product metadata*" in place m_{42}.

The transition Z_{10} interprets the activities "*Distribution of data to be exported in accordance with the type of the transport mechanism – 'Streaming' or 'Storage'* ".

$Z_{10} = < \{m_{40}, m_{41}, m_{42}\}, \{m_{43}, m_{44}\},$

	m_{43}	m_{44}	
m_{40}	$W\ m_{40},m_{43}$	$W\ m_{40},m_{44}$	
m_{41}	$W\ m_{41},m_{43}$	$W\ m_{41},m_{44}$	>,
m_{42}	$W\ m_{42},m_{43}$	$W\ m_{42},m_{44}$	

where: $W\ m_{40},m_{43} = W\ m_{41},m_{43} = W\ m_{42},m_{43}$ = "*The TV product data will be transmitted by File Transfer*";

$W m_{40},m_{44} = W m_{41},m_{44} = W m_{42},m_{44}$ = "*The TV product data will be transmitted by Streaming*"

The tokens obtain the characteristics as follows:

- "*TV products data for export by File Transfer*" in place m_{43};
- "*TV product data for export by Streaming*" in place m_{44}.

The transition $Z_{0.6}$ interprets the activities "*Organizing of the output data in a Wrapper storage structure suitable for File Transfer*".

The tokens obtain the characteristics as follows:

- "*Wrapped data which are ready for sending by File Transfer*" in place e_4.

$Z_{0.6}$ = < {l_7 , l_8 , m_{43}}, { e_4},

	e_4	
l_7	true	
l_8	true	>,
m_{43}	true	

The transition $Z_{0.7}$ interprets the activities "*Organizing of the output data in a suitable Wrapper or Elementary Streaming transport structure*".

The tokens obtain the characteristics as follows:

- "*Data for sending by SDI Streaming*" in place e_5;
- "*Data for sending by Streaming, which are wrapped on the mode, corresponding to the required transport technology*" in place e_6;
- "*Playout schedules of the TV products*" in place e_7;
- "*Playout schedules of the Editorial products*" in place e_8.

$Z_{0.7}$ = < {l_9 , l_{10}, m_{44}}, { e_5, e_6, e_7, e_8},

	e_5	e_6	e_7	e_8	
l_9	false	true	false	true	
l_{10}	false	true	false	false	>,
m_{44}	W m_{44},e_5	W m_{44},e_6	true	false	

where: W m_{44},e_5 = "*The TV product data will be sent by SDI Streaming*";

W m_{44},e_6 = "*The TV product data will be sent by means of Wrapper Streaming mechanism*".

4. The modelling method: a tool for making efficient project decisions

The functional model proposed in *Section 3.* allows us to describe each particular realization of network-based production systems in a most economical way, and in detail (see the Appendix).

Thus, for example, the function C (which gives the capacities of the places described here) allows us to characterize, both qualitatively and quantitatively, the basic functional modules of the subsystem. By giving "0" value to the capacities C_l, C_m and C_e, individual places and entire transitions from the base platform model can be eliminated. In this manner, as shown in *Table 1* (on the next page), functional models can be obtained of any of the most typical production processes [3][4].

On this basis, any project decision for the development of an integrated network production facility can be interpreted.

Consequently, the software realization of the functional model could be used as a valuable practical instrument for making efficient project decisions.

TV Production type	Place capacities which have "0" value
Ordinary studio (OB van) production	$Cm_{11} = Cm_{12} = Cm_{18} = Cm_{19} = Cm_{20} = Cm_{21} = Cm_{22} = Cm_{23} = Cm_{24} = Cm_{25} = Cm_{26} = Cm_{27} = Cm_{28} = Cm_{29} = Cm_{30} = Cm_{31} = Cm_{32} = Cm_{33} = Ce_7 = 0$
Virtual studio production	$Ce_7 = 0$
Ordinary postproduction	$Cl_4 = Cl_{12} = Cl_{13} = Cl_{14} = Cm_{12} = Cm_{13} = Cm_{18} = Cm_{19} = Cm_{20} = Cm_{21} = Cm_{22} = Cm_{23} = Cm_{24} = Cm_{28} = Cm_{29} = Cm_{31} = Ce_7 = Ce_8 = 0$
Virtual postproduction	$Cl_4 = Cl_{12} = Cl_{13} = Cl_{14} = Cm_{13} = Ce_7 = Ce_8 = 0$
Subtitling and overdubbing of the sound, on foreign TV broadcasts	$Cl_4 = Cl_{12} = Cl_{13} = Cl_{14} = Cm_{11} = Cm_{12} = Cm_{13} = Cm_{18} = Cm_{19} = Cm_{20} = Cm_{21} = Cm_{22} = Cm_{23} = Cm_{24} = Cm_{25} = Cm_{26} = Cm_{27} = Cm_{28} = Cm_{29} = Cm_{30} = Cm_{31} = Cm_{32} = Cm_{33} = Cm_{36} = Cm_{37} = Cm_{38} = Ce_7 = Ce_8 = 0$
TV news production and transmission	$Cm_{11} = Cm_{12} = Cm_{18} = Cm_{19} = Cm_{20} = Cm_{21} = Cm_{22} = Cm_{23} = Cm_{24} = Cm_{25} = Cm_{26} = Cm_{27} = Cm_{28} = Cm_{29} = Cm_{30} = Cm_{31} = Cm_{32} = Cm_{33} = 0$
Archiving of TV products	$Cl_{14} = Cl_{15} = Cm_{10} = Cm_{12} = Cm_{13} = Cm_{18} = Cm_{19} = Cm_{20} = Cm_{21} = Cm_{22} = Cm_{23} = Cm_{24} = Cm_{27} = Cm_{28} = Cm_{29} = Cm_{30} = Cm_{32} = Cm_{34} = Cm_{35} = Cm_{36} = Cm_{37} = Cm_{38} = Cm_{39} = Ce_7 = Ce_8 = 0$
Broadcasting of TV products	$Cl_2 = Cl_4 = Cl_7 = Cl_9 = Cl_{12} = Cl_{13} = Cl_{14} = Cl_{15} = Cl_{16} = Cm_8 = Cm_{11} = Cm_{12} = Cm_{13} = Cm_{15} = Cm_{18} = Cm_{19} = Cm_{20} = Cm_{21} = Cm_{22} = Cm_{23} = Cm_{24} = Cm_{25} = Cm_{26} = Cm_{27} = Cm_{28} = Cm_{29} = Cm_{30} = Cm_{31} = Cm_{32} = Cm_{33} = Cm_{38} = Cm_{43} = Ce_8 = 0$

Table 1
Place capacities not required for typical production processes.

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Appendix
The concept of Generalized Nets

Generalized Nets (GNs) are extensions and modifications of ordinary Petri Nets. Basic results on GNs are published in a series of about 100 papers in the "AMSE Press" series.

Other information about Petri Nets and GNs can be found at:

www.daimi.aau.dk/PetriNets/bibl/aboutpnbibl.html

GNs are defined in a way that is principally different from the ways of defining the other types of Petri Nets. The first basic difference between GNs and ordinary Petri Nets is the "place-transition" relationship. Here, transitions are objects of a more complex nature. A transition may contain *m* input and *n* output places (see *Fig. A1*.) where m, n ≥ 1.

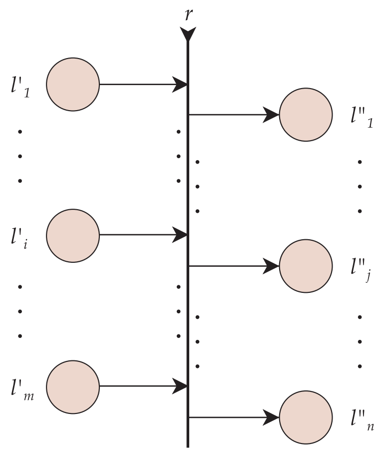

Figure A1
A transition may contain *m* input and *n* output places.

Formally, every transition is described by a septuplicate:

$$Z = \langle\ L', L'', t_1, t_2, r, M, \square\ \rangle$$

where:

(a) *L*' and *L*" are finite, non-empty, sets of places (the transition's input and output places, respectively). For the transition in *Fig. A1*, these are $L' = \{ l'_1, l'_2, \ldots, l'_m \}$ and $L'' = \{ l''_1, l''_2, \ldots, l''_n \}$;

(b) t_1 is the current time-moment of the transition's firing;

(c) t_2 is the current value of the duration of its active state;

(d) r is the transition's *condition* that determines which tokens will pass (or *transfer*) from the transition's inputs to its outputs; it has the form of an IM:

$$r = \begin{array}{c|ccccc} & l''_1 & \cdots & l''_j & \cdots & l''_n \\ \hline l'_1 & & & & & \\ \vdots & & & r_{i,j} & & \\ l'_i & & & (r_{i,j} - \text{predicate}) & & \\ \vdots & & & (1 \le i \le m,\ 1 \le j \le n) & & \\ l'_m & & & & & \end{array} ;$$

$r_{i,j}$ is the predicate which corresponds to the i-th input and j-th output places. When its truth value is "true", a token from the i-th input place can be transferred to the j-th output place; otherwise, this is not possible;

(e) M is an IM of the capacities of the transition's arcs:

$$M = \begin{array}{c|ccccc} & l''_1 & \cdots & l''_j & \cdots & l''_n \\ \hline l'_1 & & & & & \\ \vdots & & & m_{i,j} & & \\ l'_i & & & (m_{i,j} \ge 0 - \text{natural number}) & & \\ \vdots & & & (1 \le i \le m,\ 1 \le j \le n) & & \\ l'_m & & & & & \end{array} ;$$

(f) □ is an object having a form similar to a Boolean expression. It may contain as variables the symbols which serve as labels for the transition's input places, and is an expression built up from variables and the Boolean connectives $\wedge$ and $\vee$ whose semantics are defined as follows:

$\wedge(l_{i_1}, l_{i_2}, \ldots, l_{i_u})$ – every place $l_{i_1}, l_{i_2}, \ldots, l_{i_u}$ must contain at least one token

$\vee(l_{i_1}, l_{i_2}, \ldots, l_{i_u})$ – there must be at least one token in all places $l_{i_1}, l_{i_2}, \ldots, l_{i_u}$, where $\{l_{i_1}, l_{i_2}, \ldots, l_{i_u}\} \subset L'$

When the value of a type (calculated as a Boolean expression) is "*true*", the transition can become active, otherwise it cannot.

The ordered quadruplicate:

$$E = \langle \langle A, \pi_A, \pi_L, c, f, \theta_1, \theta_2\rangle, \langle K, \pi_K, \theta_K\rangle, \langle T, t^0, t^*\rangle, \langle X, \Phi, b\rangle\rangle$$

is called a *Generalized Net* (GN) if:

(a) A is a set of transitions;

(b) π_A is a function giving the priorities of the transitions, i.e. $\pi_A : A \to N$, where $N = \{0, 1, 2,\ldots\} \cup \{\infty\}$;

(c) π_L is a function giving the priorities of the places, i.e. $\pi_L : L \to N$, where $L = pr_1 A \cup pr_2 A$, and $pr_i X$ is the i-th projection of the n-dimensional set, where $n \in N$, $n \geq 1$ and $1 \leq k \leq n$ (obviously, L is the set of all GN places);

(d) c is a function giving the capacities of the places, i.e. $c : L \to N$;

(e) f is a function which calculates the truth values of the predicates of the transition's conditions (for the GN described here, let the function f have the value "*false*" or "*true*", i.e. a value from the set $\{0,1\}$;

(f) θ_1 is a function giving the next time-moment when a given transition Z can be activated, i.e. $\theta_1(t) = t'$, where $pr_3 Z = t$, $t' \in [T, T + t^*]$ and $t \leq t'$. The value of this function is calculated at the moment when the transition terminates its functioning;

(g) θ_2 is a function giving the duration of the active state of a given transition Z, i.e. $\theta_2(t) = t'$, where $pr_4 Z = t \in [T, T + t^*]$ and $t' \geq 0$. The value of this function is calculated at the moment when the transition starts functioning;

(h) K is the set of the GN's tokens. In some cases, it is convenient to consider this set in the form:

$$K = \bigcup_{l \in Q^I} K_l$$

where K_l is the set of tokens which enter the net from place l, and Q^I is the set of all input places of the net;

(i) π_K is a function giving the priorities of the tokens, i.e. $\pi_K : K \to N$;

(j) θ_K is a function giving the time-moment when a given token can enter the net, i.e. $\theta_K(\alpha) = t$, where $\alpha \in K$ and $t \in [T, T + t^*]$;

(k) T is the time-moment when the GN starts functioning. This moment is determined with respect to a fixed (global) time-scale;

(l) t^0 is an elementary time-step, related to the fixed (global) time-scale;

(m) t^* is the duration of the GN functioning;

(n) X is the set of all initial characteristics the tokens can receive when they enter the net;

(o) Φ is a characteristic function which assigns new characteristics to every token when it makes a transfer from an input to an output place of a given transition;

(p) b is a function giving the maximum number of characteristics a given token can receive, i.e. $b : K \to N$.

For example, if $b(\alpha) = 1$ for some token α, then this token will enter the net with some initial characteristic (marked as its zero-characteristic) and subsequently it will keep only its current characteristic.

When $b(\alpha) = \infty$, the token α will keep all its characteristics. When $b(\alpha) = k < \infty$, except its zero-characteristic, the token α will keep its last k characteristics (characteristics older than the last k

will be "forgotten"). Hence, in the general case, every token α has $b(\alpha)+1$ characteristics when it leaves the net.

A GN may not have some of the components, and such GNs give rise to special classes of GNs called *reduced GNs*.

Let us define the set of the GN's components:

$$\Omega = \{A, \pi_A, \pi_L, c, f, \theta_1, \theta_2, K, \pi_K, \theta_K, T, t^0, t^*, X, \Phi, b\} \cup \{A_i \mid 1 \le i \le 7\}$$

where $A_i = pr_i A$ $(1 \le i \le 7)$, i.e. $A_i \in \{L', L'', t_1, t_2, r, M, \square\}$ and let $Y \in \Omega$

Let Σ be the class of all GNs. Σ is a proper class in set-theoretical sense.

By means of Σ^Y we will denote the class of those GNs which do not have a Y-component. The elements of Σ^Y will be called "*Y-reduced GNs*".

In this Appendix, a GN from the following reduced class is used:

$$\Sigma^{A_3,\ A_4,\ A_6,\ A_7,\ \pi_A,\ \pi_L,\ c,\ f,\ \theta_1,\ \theta_2,\ \pi_K,\ \theta_K,\ T,\ t^o,\ t^*,\ b}$$

Different operations and relations are defined over the transitions of the GNs and over the same nets.

The idea of defining operators over the set of GNs in the form suggested below dates back to 1982. Today, the operator aspect has an important place in the theory of GNs. Six types of operators are defined in its framework. Every operator assigns to a given GN, a new GN with some desired properties. The six types of operators are:

1) global (G–) ;
2) local (P–);
3) hierarchical (H–);
4) reducing (R–);
5) extending (O–);
6) dynamical (D–).

G*lobal operators* transform an entire given net or all its components of a given type, according to a definite procedure. They include operators that alter (i) the form and structure of the transitions (G_1, G_2, G_3, G_4, G_6); (ii) the temporal components of the net (G_7, G_8); (iii) the duration of its functioning (G_9); (iv) the set of tokens (G_{10}); (v) the set of initial characteristics (G_{11}); (vi) the characteristic function of the net (G_{12}) (this is a function which is the union of all places' characteristic functions); (vii) the evaluation function (G_{13}), and (viii) the functions of other nets (G_5, G_{14}, …, G_{20}).

The second type of operators are *local operators*. They transform single components of some of the transitions of a given GN. There are three types of local operators:

- temporal (P_1, P_2, P_3, P_4), which change temporal components of a given transition;

- matrix (P_5, P_6), which change some of the index matrices of a given transition;
- other operators which alter the transition's type (P_7), the capacity of some of the places in the net (P_8) or the characteristic function of an output place (P_9), or the evaluation function associated with the transition condition predicates of the given transition (P_{10}).

For any of these operators, a continuation (P_i, $1 \leq i \leq 10$) to a global one ($\overline{P_i}$, $1 \leq i \leq 10$) can be made by defining the corresponding operator in such a way that it would transform all components of a specified type in every transition of the net.

The third type of operators are the *hierarchical operators*. The hierarchical operators H_1 and H_3 replace a given place or transition, respectively, of a given GN with a whole new net. Conversely, operators H_2 and H_4 replace a part of a given GN with a single place (H_2) or transition (H_4). Finally, the operator H_5 changes a subnet of a given GN with another subnet. Expanding operators can be viewed as tools for magnifying the modelled process's structure; shrinking operators can be viewed as a means of integrating and ignoring the irrelevant details of the process.

The next (fourth) group of operators produce a new, reduced GN from a given net. They allow the construction of elements of the classes of reduced GNs. To find the place of a given Petri net modification among the classes of reduced GNs, it must be compared to a reduced GN obtained by an operator of this type. These operators are called *reducing operators*.

Operators from the fifth group extend a given GN. These *extending operators* are associated with every one of the GN extensions. They are:

- operators extending a given GN to a fuzzy and intuitionistic fuzzy GN of a respective type (O_1, O_2, $\overline{O_1}$, …, $\overline{O_5}$);
- an operator replacing the firing moment of a given transition in a given GN with an interval – and its extension: a global operator doing the same over all transitions of the net (O_6, $\overline{O_6}$); and operators doing the opposite (O_7, $\overline{O_7}$);
- operators which paint the tokens and the arcs of a given GN ($\overline{O_8}$) or which do the opposite ($\overline{O_9}$);
- an operator which adds a "memory" component to the structure of a given GN ($\overline{O_{10}}$), and one which removes such components ($\overline{O_{11}}$);
- operators which transform a given GN to a GN with optimization components (O_{12}, $\overline{O_{12}}$), and an operator which removes such components from the GN ($\overline{O_{13}}$);
- operators which transform a given GN to a GN with additional clocks (O_{14}, $\overline{O_{14}}$), or which modify a GN with additional clocks to a GN without such components ($\overline{O_{15}}$);
- operators which transform a given GN to a GN with complex transition types (O_{16}, $\overline{O_{16}}$), and one which removes such components ($\overline{O_{17}}$);
- operators which transform a given GN to a GN with transition stop conditions (O_{18}, $\overline{O_{18}}$), and one which removes such components ($\overline{O_{19}}$);

*In 1967, **Angel Deliysky** graduated with an M.Sc. in Electrical Engineering (Electronics and Computers) from the Technical University in Sofia. That year, he joined the Technical Department of Bulgarian National Television (BNT) as a maintenance engineer and eventually became head of the group.*

In 1972, Mr Deliysky became a departmental manager and went on in 1981 to become BNT's Manager of TV Broadcast Automation. From 1995 until 1997, he was Deputy Technical Director and Head of the BNT Centre for TV Technologies Development. Presently, he is R&D Manager of TV Technology in BNT.

In 1979, under the auspices of the ITU, Angel Deliysky received specialist training in the automation of TV broadcasts production, at the premises of various TV broadcast companies in West Germany, Austria and Switzerland. Two years later, he received further training in this field from Bosch-Fernseh in West Germany. In 1985, he obtained a Ph.D. in Electrical Engineering (TV Broadcast Production) in Sofia and, in 1996, became Associate Professor/Senior Research Collaborator in the field of TV computer technologies.

- operators which transform a given GN to a GN with a (global) stop condition ($\overline{O}_{20}$), and one which removes this component from the GN ($\overline{O}_{21}$);

- an operator which transforms a given GN to a two-way GN ($\overline{O}_{22}$).

Finally, the operators from the sixth and last group are related to the ways of the GN functioning, so they are called *dynamical operators*. They are as follows:

- operators $D(1,i)$ which determine the procedure for evaluating the transition condition predicates ($1 \le i \le 18$);

- operators which govern token-splitting: one which allows splitting ($D(2, 1)$) and one which prohibits splitting ($D(2, 2)$); and operators which govern the union of tokens having a common predecessor – ($D(2, 4)$) which allows, and ($D(2, 3)$) which prohibits the union;

- operators which determine the strategies of the token's transfer: one-at-a-time vs. in groups (the operator $D(3, 2)$ allows this whereas the operator $D(3, 1)$ does not allow it);

- operators which relate to the ways of evaluating the transition condition predicates: predicate checking ($D(4, 1)$); changing the predicates by probability functions with corresponding forms ($D(4, 2)$); expert estimations of predicate values ($D(4, 3)$); predicates depending on solutions to optimization problems (e.g. a transportation problem) ($D(4, 4)$).

These different types of operators, as well as the others that can be defined, have a major theoretical and practical value. On the one hand, they help us to study the properties and the behaviour of GNs. On the other, they facilitate the modelling of many real processes.