Generalized Net Model of a Length-Gauge Measurement Process

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Abstract: Generalized Nets Integrated Development Environment (GN IDE) is a simulation tool for GN models. In the paper the GN model of a length-gauge measurement process is defined and simulate in GN IDE. Real calibration of a stop-end length gauge sized 50mm is performed from six persons (subjects) in the Central Laboratory for Measuring Equipment at the Prof. Tsvetan Lazarov Institute of Defence. The data is used in the simulation. Part of the code and graphics that demonstrates tokens movement, the change of the characteristics of the tokens and the relationship between subject evaluation and measurement result are shown.
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1 Description of the Process of Measuring Plane-Parallel Stop-End Length Gauges

The process of measuring plane-parallel stop-end length gauges – gauge blocks (GBs), object of this study, is realized by the generalized net presented on Fig. 1.

The generalized-net model of the measurement process (MP) of GBs is consistent with the activities carried out in the Central Laboratory for Measuring Equipment at the Prof. Tsvetan Lazarov Institute of Defence,

verifying it by real calibration of a stop-end length gauge sized 50 mm. The described processes are based on real experiments.

Every plane-parallel stop-end length gauge subject to measurement in the generalized net will be presented by a token denoted by "GBObject", and the subject involved in the measurement process – by a token denoted by "subject". The measurement process is subdivided into eight stages (subprocesses):

- first stage - analyzing the initial state;
- second stage - processing and preparing the GB incoming for calibration;
- third stage - tempering the GB and the instrumentation involved in the measurement;
- fourth stage - preparing and adjusting the measurement instrumentation;
- fifth step - measuring the object parameters;
- sixth step – data processing to obtain an estimate of the output quantity;
- seventh stage - data processing to obtain an extended measurement uncertainty;
- eighth stage - analyzing the result.

The first stage of measuring the GB is connected with analyzing the initial state. The process is performed by firstly waiting for the incoming of a particular object of measurement (object) and assessing the possibilities for measurement. The latter includes:

- check for availability of serial (factory) number and class of accuracy of the GB set
- verification of compliance with the laboratory capabilities (standards, technical auxiliary equipment, necessary resources)
- assessment whether the object can be measured or not

If the resulting assessment of the possibilities for measurement is negative, the measurement process is suspended. If there is a possibility the object to be measured, we pass to preparing and admitting the object. The admission is carried out by the specialist (subject), responsible for measurement, and includes the following steps:

- completing a request
- coordinating the request
- filing objects (each object is identified by a unique sticker with brief details)

During the object admission, additionally assessed is whether it is possible to continue the measurement activities. If the assessment is positive, the stage

of analysis of the initial state ends and we proceed to the processing and preparing of the GB, or otherwise the measurement process is suspended.

The second stage of measurement is connected with processing and preparing the incoming GB for calibration (object) and its corresponding gauge in nominal size.

The process is carried out by cleaning very well the gauges from the conserving lubricant, using pure anhydrous and acid-free benzine and a clean cotton cloth, and placing them on special check-up holders (labelled with their respective identification numbers), then performing outward examination and assessment for lack of visible defects, traces of corrosion, dirt, scratches, etc. Each gauge must be marked with nominal size.

The third stage of the measurement is connected with tempering of the GB and the instrumentation involved in the measurement. The process is carried out by placing the cleaned objects (*object* and reference gauge) close to the measurement system in the laboratory room for measurement. Before beginning the tempering, the measurement system (measurement unit of the comparator) is prepared, then a combined device for recording the temperature and humidity of the environment is placed near the measurement system (comparator). To monitor the steel temperature, a contact thermometer is placed on the measurement table of the comparator.

Before starting the calibration, ambient temperature in the room is maintained for 4 hours in the range 20°C ± 0.5°C. This is a process of waiting until achieving mutual heat transfer and equalization of the temperatures of the GB to be measured (object), comparator and environment.

It is important to note that the difference in temperature between the reference and object, as well as non-compliance with the requirement the ambient temperature to be in the range 20 ± 0,5°C, leads to the emergence of temperature errors. Offsetting these deviations mathematically takes much time, requires highly trained personnel and is a prerequisite for the emergence of subjective errors. Therefore, to achieve maximum accuracy in the measurements and subsequent analysis of the results, it is crucial to observe the temperature regime and the algorithm prescribed for measurement and calculation.

The fourth stage of the measurement is related to preparing and adjusting the measurement instrumentation. The process is performed by successively preparing the necessary auxiliary equipment (heat shield, thermohygrometer, contact thermometer, measurement protocol, cotton gloves), supplying power to the device controlling the comparator and setting the measurement unit into initial operating position, placing the object (object) into the measurement

unit, and checking and recording the data from the thermohygrometer and contact thermometer.

*The **fifth stage*** of the measurement is related to measuring the object parameters.

The process takes place in three steps:

- checking the stability of the indication by repeatedly positioning in the center of the reference and recording the value
- lifting the measurement ending of the upper converter through the manipulator and moving it so that the middle of the calibrated gauge (object) falls under the measurement ending; checking the stability of the indication and recording the value; in this way, 10 measurements are carried out
- checking the plane-parallelism (deviation from flatness) by measuring the length of the calibrated gauge (object) in the middle and at the four corners of the measurement surface. The final result is formed as the difference between the biggest and smallest indication.

*The **sixth stage*** of the measurement is related to data processing to obtain an estimate of the output quantity. The target information (the result) is generated on the basis of the measured object parameters. The tolerances of the measured value to the target in terms of average size and flatness are in accordance with Bulgarian State Standard EN ISO 3650 [3].

*The **seventh stage*** of measurement is related to data processing to obtain an extended measurement uncertainty. The processing itself is carried out according to a mathematical model referred to in EA-4/02 [4]. Each quantity associated with the measurement uncertainty is characterized by the following data: estimate (x_i), root mean square uncertainty $u(x_i)$, probability distribution, coefficient of sensitivity and individual contributions of the uncertainty – $u_i(y)$.

*The **eighth stage*** (last) of measurement is related to the analysis of the result. This stage includes analysis of the results obtained in terms of the overall assessment of the object and its designation as fit, partially fit or unfit for use.

2   Definition of a Generalized Net of the Process of Measuring a GB

The developed generalized-net model simulates the above-described stages of measuring a GB. The model is shown in Fig. 1.
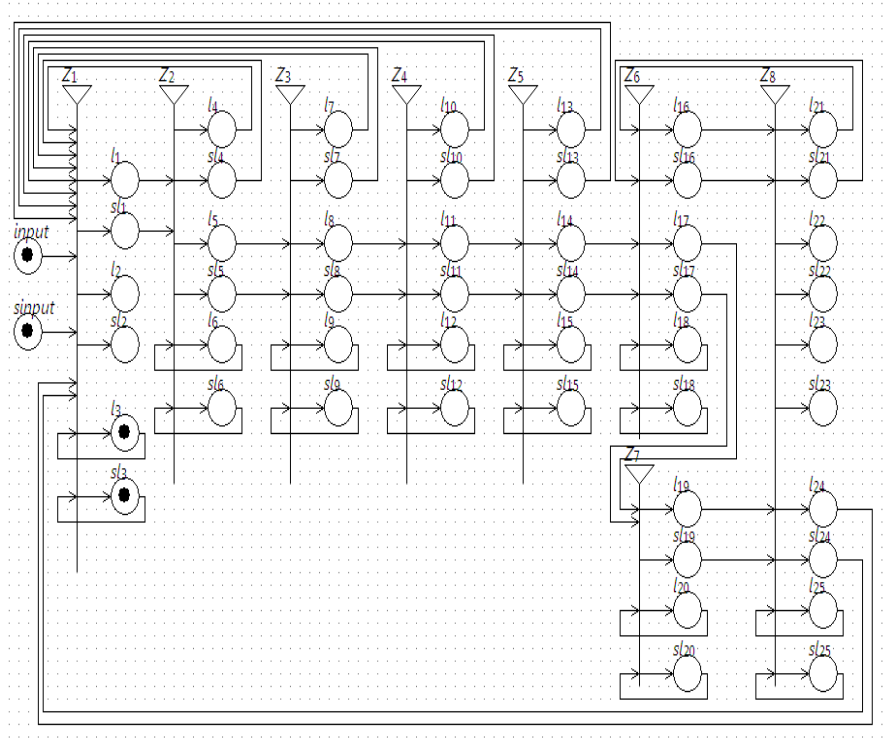
39

Figure 1. GN model of MP for a GB.

Initialization of the input

In position *input* of the generalized net of Fig. 1, a token $GBObject$ is generated with a set of characteristics
($state, serialNumber, accuracy, nominal, material, status$) with initial values respectively:

- $state$ (the current state of the measurement process for the GB) – *"Plane-parallel stop-end length gauge incoming for measurement";*
- $serialNumber$ - serial (factory) number of the GB;
- $accuracy$ - class of accuracy of the GB set;
- $nominal$ - nominal value;
- $material$ – material;
- $status$ - outward condition.

In position *sinput* of the generalized net, a token *subject* is generated with a set of characteristics:

$(state, name, experianceDegree, objectStateDegree,$
$objectWorkingConditionsDegree,$
$subjectAreaKnowledgeDegree, personalQualitiesDegree,$
$resourcesDegree,$
$regulationsDegree, motivationDegree, complexDegree)$

with initial values respectively:

- $state$ - „*Subject accepted to perform GB measurement*";
- $name$ - name of the subject that will performs measurement;
- $experianceDegree$ - degree of runtime of the subject in the field of measurements and in particular for certain types of measurement;
- $objectStateDegree$ - degree of knowledge of information on the state of the object (the metrological characteristics of the particular subject over the years, and data analysis of baseline);
- $objectWorkingConditionsDegree$ - degree of familiarity with the necessary information regarding the calibration object;
- $subjectAreaKnowledgeDegree$ - degree possession of necessary knowledge, education and training;
- $personalQualitiesDegree$ - degree possession of personal (professional and moral) qualities;
- $resourcesDegree$ - degree of knowledge necessary reference and auxiliary equipment, tools, etc.;
- $regulationsDegree$ - level of knowledge and application of normative documents used in their daily activities;
- $motivationDegree$ - degree of motivation aimed at achieving specific results, goals, positions, values that are responsible for the behavior of the subject;
- $complexDegree$ - extent of complete performance of the subject as to the suitability for the task „measurement of the object (GB) ".

The degrees are numbers in the closed interval [0,1].

Initially tokens *listenGBObject* and *listenSubject* are in places in l_{26} and sl_{26}. The token *listenGBObject* has three characteristics:

expandedUncertaintyHistory,
deviationFromAverageSizeHistory and
deviationFromFlatnessHistory. The token *listenSubject* is generated
with a set of characteristics:
(experianceDegreeHistory, objectStateDegreeHistory,
objectWorkingConditionsDegreeHistory, subjectAreaKnowledgeDegreeHistory,
personalQualitiesDegreeHistory, resourcesDegreeHistory,
regulationsDegreeHistory, motivationDegreeHistory, complexDegreeHistory)

They will stay in these places throughout the GN simulation and they will
accumulate in their characteristics values of measurements and assessments
of the subject respectively. These two tokens will be used for gathering the
history of the measurements.

D*efinition of the transitions of the generalized net*

The generalized net simulating the process of measuring a GB consists of
eight transitions with names respectively Z_1.........Z_8.

$$. A = \{Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7, Z_8\},$$

where:
- Z_1 – describes the analyzing of the initial state;
- Z_2 – describes the processing and preparing of the reference and
  calibrated GB;
- Z_3 – describes the tempering of the GB and the instrumentation
  involved in the measurement;
- Z_4 – describes the preparing and adjusting of the measurement
  instrumentation;
- Z_5 – describes the measurement of the object (GB) parameters;
- Z_6 – describes the data processing to obtain an estimate of the output
  quantity or measurement error;
- Z_7 – describes the data processing to obtain the measurement
  uncertainty;
- Z_8 – describes the analyzing of the measurement result (set of
  values variable copied the measurand together with any other
  available relevant information).

The indexed matrices of the capacities of arcs M will be filled with values
"infinity", since restriction should not be imposed on the number of tokens
traversing the arcs. For the net transitions, time components t_1 (current time
moment at which the transition is activated), t_2 (current duration of the
transition's active state) will have values "0" and "-1", respectively, i.e. the

transition is activated with the start of the GN and has infinite duration of the active state.

By default it is assumed that each GB incoming for measurement (tokens *GBObject*) has a lower priority than those adopted before it. Accordingly, any place of the GN realizing standstill of the resources and/or factors of the environment also has a higher priority.

Definition of transition Z_1

$$Z_1 = \langle \{s_{input}, sl_3, sl_7, sl_{10}, sl_{13}, sl_{24}, input, l_3, l_7, l_{10}, l_{13}, l_{24}\},$$
$$\{sl_1, sl_2, sl_3, l_1, l_2, l_3\}, t_1, t_2,$$
$$r_1, M, \wedge \ (\vee \ (s_{input}, sl_3, sl_7, sl_{10}, sl_{13}, sl_{24}),$$
$$\vee \ (input, l_3, l_7, l_{10}, l_{13}, l_{24})) \rangle$$

where:

r_1	sl_1	sl_2	sl_3	l_1	l_2	l_3
s_input	$\neg W_{1,2}$ $\wedge W_{1,1}$	$\neg W_{1,2}$ $\wedge \neg W_{1,1}$	$W_{1,2}$	F	F	F
sl_3			$W_{1,2}$	F	F	F
sl_7	$\neg W_{1,2}$ $\wedge W_{1,1}$	$\neg W_{1,2}$ $\wedge \neg W_{1,1}$	T	F	F	F
sl_{10}			T	F	F	F
sl_{13}	F	F	T	F	F	F
sl_{24}	F	F	T	F	F	F
	F	F				
	F	F				

input	F	F	F	$\neg W_{1,2} \wedge W_{1,1}$	$\neg W_{1,2} \wedge \neg W_{1,1}$	$W_{1,2}$
l_3	F	F	F	$\neg W_{1,2} \wedge W_{1,1}$	$\neg W_{1,2} \wedge \neg W_{1,1}$	$W_{1,2}$
l_7	F	F	F	F	F	T
l_{10}	F	F	F	F	F	T
l_{13}	F	F	F	F	F	T
l_{24}	F	F	F	F	F	T

The indexed matrix of predicates r_1 is described via the following denotations:
- T - „*true*";
- F - „*false*";
- $W_{1,1}$ – predicate determining whether the subject has decided that the object complies with the requirements;
- $W_{1,2}$ – predicate determining whether the subject has decided that standby mode is necessary to estimate the object (resources, factors of the environment).

As a result of the transition Z_1, the token *subject* goes to:
- place sl_1, if the analysis has been conducted, the gauge characteristics are estimated and they are consistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"taken decision for compliance with the requirements";*
- place sl_2, if the analysis has been conducted, the gauge characteristics are estimated and they are inconsistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"taken decision for non-compliance with the requirements";*
- place sl_3, if the necessary resources and/or environment factors are not available to analyze the initial state, the characteristic "*state*" getting value *"taken decision for awaiting resources for analyzing the initial state";*

As a result of the transition Z_1, the token *GNObject* goes to:

- place l_1, if the analysis has been conducted, the gauge characteristics are estimated and they are consistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"initial state in compliance with the requirements";*
- place l_2, if the analysis has been conducted, the gauge characteristics are estimated and they are inconsistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"initial state in non-compliance with the requirements";*
- place l_3, if the necessary resources, environment factors and/or subjects are not available to analyze the initial state, and the characteristic "*state*" gets value *"awaiting resources for analyzing the initial state".*

Definition of transition Z_2

$$Z_2 = \langle \{sl_1, sl_6, l_1, l_6\}, \{sl_4, sl_5, sl_6, l_4, l_5, l_6\}, t_1, t_2, r_2, M, \wedge (\vee (sl_1, sl_6), \vee (l_1, l_6))\rangle,$$

where:

r_2	sl_4	sl_5	sl_6	l_4	l_5	l_6
sl_1	$\neg W_{2,2}$ $\wedge \neg W_{2,1}$	$\neg W_{2,2}$ $\wedge W_{2,1}$	$W_{2,2}$	F	F	F
sl_6	$\neg W_{2,2}$ $\wedge \neg W_{2,1}$	$\neg W_{2,2}$ $\wedge W_{2,1}$	$W_{2,2}$	F	F	F
l_1	F	F	F	$\neg W_{2,2}$ $\wedge \neg W_{2,1}$	$\neg W_{2,2}$ $\wedge W_{2,1}$	$W_{2,2}$
l_6	F	F	F	$\neg W_{2,2}$ $\wedge \neg W_{2,1}$	$\neg W_{2,2}$ $\wedge W_{2,1}$	$W_{2,2}$

The indexed matrix of predicates r_2 is described via the following denotations:

- F – „*false*" ;
- $W_{2,1}$ – predicate determining whether the subject has decided that preliminary processing and preparing the gauge is possible;

- $W_{2,2}$ – predicate determining whether the subject has decided to await the preliminary processing of the object (resources, factors of the environment).

As a result of the transition Z_2, the token *subject* goes to:
- place sl_4, on the occurrence of an event which has upset the processing and preparing of the gauges and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"taken decision to suspend or renew the MP from the beginning due to a problem in the GB processing"*;
- place sl_5, if the processing has been conducted and the gauge is consistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"taken decision for compliance with the requirements after the GB processing"*;
- place sl_6, if the necessary resources and/or environment factors are not available to process the gauges and the characteristic "*state*" gets value *"taken decision for awaiting resources for preliminary object processing"*.

As a result of the transition Z_2, the token *GBObject* goes to:
- place l_4, on the occurrence of an event which has upset the processing and preparing of the gauges and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"problem in the GB processing"*;
- place l_5, if the processing has been conducted and the gauge is consistent with the requirements for measuring a GB, the characteristic "*state*" getting value "processed GB";
- place l_6, if the necessary resources and/or environment factors are not available to process the gauges and the characteristic "*state*" gets value *"awaiting resources for the gauge processing"*.

Definition of transition Z_3

$$Z_3 = \langle \{sl_5, sl_9, l_5, l_9\}, \{sl_7, sl_8, sl_9, l_7, l_8, l_9\}, t_1, t_2, r_3, M,$$
$$\wedge (\vee (sl_5, sl_9), \vee (l_5, l_9)) \rangle$$
where:

r_3	sl_7	sl_8	sl_9	l_7	l_8	l_9
sl_5	$\neg W_{3,2} \wedge \neg W_{3,1}$	$\neg W_{3,2} \wedge W_{3,1}$	$W_{3,2}$	F	F	F
sl_9	$\neg W_{3,2} \wedge \neg W_{3,1}$	$\neg W_{3,2} \wedge W_{3,1}$	$W_{3,2}$	F	F	F
l_5	F	F	F	$\neg W_{3,2} \wedge \neg W_{3,1}$	$\neg W_{3,2} \wedge W_{3,1}$	$W_{3,2}$
l_9	F	F	F	$\neg W_{3,2} \wedge \neg W_{3,1}$	$\neg W_{3,2} \wedge W_{3,1}$	$W_{3,2}$

The indexed matrix of predicates r_3 is described via the following denotations:

- F – „$false$";
- $W_{3,1}$ – predicate determining whether the subject has decided that gauge tempering is possible;
- $W_{3,2}$ – predicate determining whether the subject has decided that GB tempering is necessary to be awaited until achieving mutual heat transfer and equalization of the temperatures of the gauges, comparator and environment.

As a result of the transition Z_3, the token *subject* goes to:

- place sl_7, on the occurrence of an event which has upset the tempering of the gauges and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"taken decision to suspend or renew the MP from the beginning due to a problem in the GB tempering"*;
- place sl_8, if the tempering has been conducted and the gauge is consistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"taken decision for compliance with the requirements after the GB tempering"*;
- place sl_9, if the necessary resources and/or environment factors are not available to temper the gauges and the characteristic "*state*" gets value *"taken decision for awaiting resources for gauge tempering"*.

As a result of the transition Z_3, the token *GBObject* goes to:

- place l_7, on the occurrence of an event which has upset the tempering of the gauges and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"problem in the GB tempering"*;
- place l_8, if the tempering has been conducted and the gauge is consistent with the requirements for measuring a GB, the characteristic "*state*" getting value *"tempered GB"*;
- place l_9, if the necessary resources and/or environment factors are not available to temper the gauges and the characteristic "*state*" gets value "*awaiting resources for gauge tempering*".

Definition of transition Z_4

$$Z_4 = \langle \{sl_8, sl_{12}, l_8, l_{12}\}, \{sl_{10}, sl_{11}, sl_{12}, l_{10}, l_{11}, l_{12}\}, t_1, t_2, r_4, M,$$
$$\wedge \left(\vee (sl_8, sl_{12}), \vee (l_8, l_{12}) \right) \rangle$$

where:

r_4	sl_{10}	sl_{11}	sl_{12}	l_{10}	l_{11}	l_{12}
sl_8	$\neg W_{4,2}$ $\wedge \neg W_{4,1}$	$\neg W_{4,2}$ $\wedge W_{4,1}$	$W_{4,2}$	F	F	F
sl_{12}	$\neg W_{4,2}$ $\wedge \neg W_{4,1}$	$\neg W_{4,2}$ $\wedge W_{4,1}$	$W_{4,2}$	F	F	F
l_8	F	F	F	$\neg W_{4,2}$ $\wedge \neg W_{4,1}$	$\neg W_{4,2}$ $\wedge W_{4,1}$	$W_{4,2}$
l_{12}	F	F	F	$\neg W_{4,2}$ $\wedge \neg W_{4,1}$	$\neg W_{4,2}$ $\wedge W_{4,1}$	$W_{4,2}$

The indexed matrix of predicates r_4 is described via the following denotations:

- F – „*false*" ;
- $W_{4,1}$ – predicate determining whether the subject has decided that preparing and adjusting the measurement instrumentation is possible;

- $W_{4,2}$ – predicate determining whether the subject has decided that preparing and adjusting the measurement instrumentation is necessary to be awaited.

As a result of the transition Z_4, the token *subject* goes to:
- place sl_{10}, on the occurrence of an event which has upset the preparation and adjustment of the measurement instrumentation, and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"taken decision to suspend or renew the MP from the beginning in preparing and adjusting the measurement instrumentation"*;
- place sl_{11}, if preparing and adjusting of the measurement instrumentation has been conducted, the characteristic "*state*" getting value *"taken decision for compliance with the requirements of the instrumentation at the GB measuring"*;
- place sl_{12}, if the necessary resources and/or environment factors are not available to prepare and adjust the measurement instrumentation, and the characteristic "*state*" gets value *"taken decision for awaiting resources for preparing and adjusting the measurement instrumentation"*.

As a result of the transition Z_4, the token *GBObject* goes to:
- place l_{10}, on the occurrence of an event which has upset the preparing and adjusting of the measurement instrumentation, and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"problem in preparing and adjusting the measurement instrumentation"*;
- place l_{11}, if preparing and adjusting of the measurement instrumentation has been conducted, the characteristic "*state*" getting value *"adjusted instrumentation for the GB measuring"*;
- place l_{12}, if the necessary resources, environment factors and/or subjects are not available to prepare and adjust the measurement instrumentation, and the characteristic "*state*" gets value *"awaiting resources for preparing and adjusting the measurement instrumentation"*.

Definition of transition Z_5

49

$$Z_5 = \langle \{sl_{11}, sl_{15}, l_{11}, l_{15}\}, \{sl_{13}, sl_{14}, sl_{15}, l_{13}, l_{14}, l_{15}\}, t_1, t_2, r_5, M,$$
$$\wedge (\vee (sl_{11}, sl_{15}), \vee (l_{11}, l_{15})) \rangle$$

where:

r_5	sl_{13}	sl_{14}	sl_{15}	l_{13}	l_{14}	l_{15}
sl_{11}	$\neg W_{5,2}$ $\wedge \neg W_{5,1}$	$\neg W_{5,2}$ $\wedge W_{5,1}$	$W_{5,2}$	F	F	F
sl_{15}	$\neg W_{5,2}$ $\wedge \neg W_{5,1}$	$\neg W_{5,2}$ $\wedge W_{5,1}$	$W_{5,2}$	F	F	F
l_{11}	F	F	F	$\neg W_{5,2}$ $\wedge \neg W_{5,1}$	$\neg W_{5,2}$ $\wedge W_{5,1}$	$W_{5,2}$
l_{15}	F	F	F	$\neg W_{5,2}$ $\wedge \neg W_{5,1}$	$\neg W_{5,2}$ $\wedge W_{5,1}$	$W_{5,2}$

The indexed matrix of predicates r_5 is described via the following denotations:
- F – „$false$" ;
- $W_{5,1}$ – predicate determining whether the subject has decided that measuring is possible;
- $W_{5,2}$ – predicate determining whether the subject has decided that awaiting the measurement is necessary.

As a result of the transition Z_5, the token *subject* goes to:
- place sl_{13}, on the occurrence of a change in the condition or an event which has upset the normal measuring (damage or change in the object characteristics, resources, etc. due to unforeseen circumstances), and the MP is necessary to be suspended or renewed from the beginning, the characteristic "state" getting value *"taken decision to suspend or renew the MP (from the beginning) at measuring";*
- place sl_{14}, if the measurement has been conducted, the characteristic "*state*" getting value *"taken decision for compliance with the requirements after the GB measuring";*

- place sl_{15}, if measuring is necessary to be awaited and the characteristic "*state*" gets value *"taken decision for awaiting measuring"*.

As a result of the transition Z_5, the token *GBObject* goes to:

- place l_{13}, on the occurrence of a change in the condition or an event which has upset normal measuring (damage or change in the object characteristics, resources, etc. due to unforeseen circumstances), the characteristic "state" getting value *"problem in measuring"*;
- place l_{14}, if the measurement has been conducted, the characteristic "*state*" getting value *"measured GB"*, while *object* gets new feature "*results*" with value array with 10 elements – the corresponding measurement data;
- place l_{15}, if measuring is necessary to be awaited and the characteristic "*state*" gets value *"awaiting measuring"*.

Definition of transition Z_6

$$Z_6 = \langle \{sl_{14}, sl_{18}, sl_{21}, l_{14}, l_{18}, l_{21}\}, \{sl_{16}, sl_{17}, sl_{18}, l_{16}, l_{17}, l_{18}\}, t_1, t_2, r_6, M,$$
$$\wedge (\vee(l_{14}, l_{18}, l_{21}), \vee(l_{14}, l_{18}, l_{21})) \rangle$$

where:

r_6	sl_{16}	sl_{17}	sl_{18}	l_{16}	l_{17}	l_{18}
sl_{14}	$\neg W_{6,2} \wedge \neg W_{6,1}$	$\neg W_{6,2} \wedge W_{6,1}$	$W_{6,2}$	F	F	F
sl_{18}			$W_{6,2}$	F	F	F
sl_{21}	$\neg W_{6,2} \wedge \neg W_{6,1}$	$\neg W_{6,2} \wedge W_{6,1}$	T	F	F	F
	F	F				
l_{14}	F	F	F	$\neg W_{6,2} \wedge \neg W_{6,1}$	$\neg W_{6,2} \wedge W_{6,1}$	$W_{6,2}$
l_{18}	F	F	F			$W_{6,2}$
l_{21}	F	F	F	$\neg W_{6,2} \wedge \neg W_{6,1}$	$\neg W_{6,2} \wedge W_{6,1}$	T
				F	F	

The indexed matrix of predicates r_6 is described via the following denotations:

- T – „$true$";
- F – „$false$";
- $W_{6,1}$ – predicate determining whether the subject has decided that additional data processing is necessary to obtain the measurement uncertainty;
- $W_{6,2}$ – predicate determining whether the subject has decided that it is necessary to await the estimating of the output quantity.

As a result of the transition Z_6, the token *subject* goes to:

- place sl_{16}, if data processing has been conducted (the output quantity estimated) and the measurement uncertainty is not necessary (this is a position that can be used when it is necessary only to check a GB or examine/analyze obtained measurement results), the characteristic "*state*" getting value *"taken decision for compliance with the requirements after processing the data from the GB measuring";*
- place sl_{17}, if data processing has been conducted and the uncertainty is necessary to be additionally measured, the characteristic "*state*" getting value *"taken decision for necessity to measure the uncertainty after processing the data from the GB measuring";*
- place sl_{18}, if it is necessary to await the data processing and estimating the output quantity, the characteristic "*state*" getting value *"taken decision for awaiting processing of the GB data".*

As a result of the transition Z_6, the token *GBObject* goes to:

- place l_{16}, if data processing has been conducted (the output quantity estimated) and the measurement uncertainty is not necessary (this is a position that can be used when it is necessary only to check a GB or examine/analyze obtained measurement results), the characteristic "*state*" getting value *"GB with obtained by evaluation of the output value"*, while *GBObject* gets 2 new characteristics *deviationFromAverageSize* and *deviationFromFlatness* with values respectively, deviation from average size and deviation from flatness;
- place l_{17}, if data processing has been conducted and the uncertainty is necessary to be additionally measured, the characteristic "*state*" getting value *"GB with obtained by evaluation of the output value and the need to obtain uncertainty"*, while *GBObject* gets 2 new characteristics *deviationFromAverageSize* and

deviationFromFlatness with values respectively, deviation from average size and deviation from flatness;

- place l_{18}, if it is necessary to await data processing and estimating of the output quantity, the characteristic "*state*" getting value *"awaiting processing of the GB data"*.

Definition of transition Z_7

$$Z_7 = \langle \{sl_{17}, sl_{20}, l_{17}, l_{20}\}, \{sl_{19}, sl_{20}, l_{19}, l_{20}\}, t_1, t_2, r_7, M,$$
$$\wedge (\vee(sl_{17}, sl_{20}), \vee(l_{17}, l_{20}))\rangle$$

where:

r_7	sl_{19}	sl_{20}	l_{19}	l_{20}
sl_{17}	$\neg W_{7,2} \wedge W_{7,1}$	$W_{7,2}$	F	F
sl_{20}	$\neg W_{7,2} \wedge W_{7,1}$	$W_{7,2}$	F	F
l_{17}	F	F	$\neg W_{7,2} \wedge W_{7,1}$	$W_{7,2}$
l_{20}	F	F	$\neg W_{7,2} \wedge W_{7,1}$	$W_{7,2}$

The indexed matrix of predicates r_7 is described via the following denotations:
- $W_{7,1}$ – predicate determining whether the subject has decided that it is possible to obtain (calculate) the measurement uncertainty;
- $W_{7,2}$ – predicate determining whether the subject has decided that it is necessary to await obtaining of the measurement uncertainty.

As a result of the transition Z_7, the token *subject* goes to:
- place sl_{19}, if the measurement uncertainty has been obtained (calculated), the characteristic "*state*" getting value *"taken decision for compliance with the requirements of the obtained (calculated) GB measurement uncertainty"*;
- place sl_{20}, if it is necessary to await obtaining of the measurement uncertainty, the characteristic "*state*" getting value *"taken decision for awaiting calculating of the measurement uncertainty"*.

As a result of the transition Z_7, the token *GBObject* goes to:
- place l_{19}, if the measurement uncertainty has been obtained (calculated), the characteristic "*state*" getting value „*GB with obtained (calculated) measurement uncertainty*";
- place l_{20}, if it is necessary to await obtaining of the measurement uncertainty, the characteristic "*state*" getting value *"awaiting calculating of the measurement uncertainty"*.

Definition of transition Z_8

$$Z_8 = \langle \{sl_{16}, sl_{19}, sl_{25}, sl_{26}, l_{16}, l_{19}, l_{25}, l_{26}\}, \{sl_{21}, sl_{22}, sl_{23}, sl_{24}, sl_{25}, \\ sl_{26}, l_{21}, l_{22}, l_{23}, l_{24}, l_{25}, l_{26}\}, t_1, t_2, r_8, M, \\ \wedge (\vee(sl_{16}, sl_{19}, sl_{25}), \vee(l_{16}, l_{19}, l_{25})) \rangle$$

where:

r_8	sl_{21}	sl_{22}	sl_{23}	sl_{24}	sl_{25}	sl_{26}	l_{21}	l_{22}	l_{23}	l_{24}	l_{25}	l_{26}
sl_{16}	$L3$	$L1$	$L2$	$L4$	$W_{8,4}$	F	F	F	F	F	F	F
sl_{19}	$L3$	$L1$	$L2$	$L4$	$W_{8,4}$	F	F	F	F	F	F	F
sl_{25}	$L3$	$L1$	$L2$	$L4$	$W_{8,4}$	F	F	F	F	F	F	F
sl_{26}	F	F	F	F	F	T	F	F	F	F	F	F
l_{16}	F	F	F	F	F	F	$L3$	$L1$	$L2$	$L4$	$W_{8,4}$	F
l_{19}	F	F	F	F	F	F	$L3$	$L1$	$L2$	$L4$	$W_{8,4}$	F
l_{25}	F	F	F	F	F	F	$L3$	$L1$	$L2$	$L4$	$W_{8,4}$	F
l_{26}	F	F	F	F	F	F	F	F	F	F	F	T

The indexed matrix of predicates r_8 is described via the following denotations:
- $W_{8,1}$ – predicate determining whether the subject has decided that there is full compliance with the requirements;
- $W_{8,2}$ – predicate determining whether the subject has decided that there is partial GB non-compliance with the laid requirements.

Objects that differ partially in some indicators can be used by those indicators which comply:

- $W_{8,3}$ – predicate determining whether the subject has decided that recalculation is necessary in Z_6 and/or Z_7;
- $W_{8,4}$ – predicate determining whether the subject has decided that it is necessary to await analyzing of the measurement result.

As a result of the transition Z_8, the token *subject* goes to:

- place sl_{21}, if it is necessary to recalculate the GB measurement result and/or measurement uncertainty, the characteristic "*state*" getting value *"taken decision for necessity to recalculate the GB measurement result";*
- place sl_{22}, if the GB measurement results are fully compliant with the requirements, the characteristic "*state*" getting value *"taken decision for compliance with the requirements after GB measuring*";
- place sl_{23}, if there is partial GB non-compliance with the laid requirements, the characteristic "*state*" getting value *"taken decision for partial non-compliance with the requirements after GB measuring*";
- place sl_{24}, if there is full non-compliance with the requirements and the MP is necessary to be suspended or renewed, the characteristic "*state*" getting value *"taken decision to suspend or renew the MP at GB measuring";*
- place sl_{25}, if it is necessary to await analyzing of the obtained results with respect to the overall object assessment, and obtaining of the required final assessment, the characteristic "*state*" getting value *"taken decision for awaiting analyzing of the obtained results".*

As a result of the transition Z_8, the token *GBObject* goes to:

- place l_{21}, if it is necessary to recalculate the GB measurement result and/or measurement uncertainty, the characteristic "*state*" getting value *"necessity to recalculate the GB measurement result";*
- place l_{22}, if the GB measurement results are fully compliant with the requirements, the characteristic "*state*" getting value *"measured GB";*
- place l_{23}, if there is partial GB non-compliance with the laid requirements, the characteristic "*state*" getting value *"measured GB with partial non-compliance*";

- place l_{24}, if there is full non-compliance with the requirements and the MP is necessary to be suspended or renewed, the characteristic "state" getting value *"measured GB with results non-compliant with the requirements";*
- place l_{25}, if it is necessary to await analyzing of the obtained results with respect to the overall object assessment, and obtaining of the required final assessment, the characteristic "*state*" getting value *"awaiting analyzing of the obtained results".*

As a result of the transition Z_8, tokens *listenGBObject* and *listenSubject* respectively goes to:
- place l_{26} and characteristics of output places l_{22}, l_{23} and l_{24} are added to history of the *listenGBObject* characteristics;
- place sl_{26} and characteristics of output places sl_{22}, sl_{23} and sl_{24} are added to history of the *listenSubject* characteristics.

3 Simulation of GN Model of a Length-Gauge Measurement Process in GN IDE

The realization of the simulation is performed by GN IDE. GN IDE is a software tool for simulation with Generalized Nets [1]. The software allows users to load and save GN XML files, to create models, to run, pause and resume simulation and to edit GN models. It implements the algorithm for transition functioning when merging of tokens is permitted which support JavaScript predicates [2]. The structure of the GN model is defined in an XML file.

Part of the code that implements the GN model of a length-gauge measurement process is shown in the following lines:

```xml
<?xml version="1.0" ?>
<gn xmlns="http://www.clbme.bas.bg/GN" name="GBs" time="256"
timeStart="0" timeStep="1" language="JavaScript" root="true">
 <transitions>
  <transition id="Z1" name="Z_{1}" priority="0" startTime="0"
lifeTime="-1" positionX="100" positionY="100" sizeY="370">
   <inputs>
    <input ref="input">
```

```xml
      <arc>
        <point positionX="50" positionY="220"/>
        <point positionX="100" positionY="220"/>
      </arc>
    </input>
    <input ref="sinput">
      <arc>
        <point positionX="50" positionY="280"/>
        <point positionX="100" positionY="280"/>
      </arc>
    </input>
    ...
  </inputs>
  <outputs>
    <output ref="l1">
      <arc>
        <point positionX="100" positionY="160"/>
        <point positionX="150" positionY="160"/>
      </arc>
    </output>
    <output ref="sl1">
      <arc>
        <point positionX="100" positionY="200"/>
        <point positionX="150" positionY="200"/>
      </arc>
    </output>
    ...
  </outputs>
  <predicates>
    <predicate input="input"
output="l1">isObjectAnalyzeSatisfyRequirements</predicate>
    <predicate input="input" output="sl1">false</predicate>
    <predicate input="input"
output="l2">isObjectAnalyzeNotSatisfyRequirements</predicate>
    <predicate input="input" output="sl2">false</predicate>
    <predicate input="input" output="l3">W_1_2</predicate>
    ...
  </predicates>
</transition>
```

```xml
    <transition id="Z2" name="Z_{2}" priority="0" startTime="0"
lifeTime="-1" positionX="200" positionY="100"
sizeY="300">...</transition>
    <transition id="Z3" name="Z_{3}" priority="0" startTime="0"
lifeTime="-1" positionX="320" positionY="100"
sizeY="300">...</transition>
    <transition id="Z4" name="Z_{4}" priority="0" startTime="0"
lifeTime="-1" positionX="440" positionY="100"
sizeY="300">...</transition>
    <transition id="Z5" name="Z_{5}" priority="0" startTime="0"
lifeTime="-1" positionX="560" positionY="100"
sizeY="300">...</transition>
    <transition id="Z6" name="Z_{6}" priority="0" startTime="0"
lifeTime="-1" positionX="680" positionY="100"
sizeY="265">...</transition>
    <transition id="Z7" name="Z_{7}" priority="0" startTime="0"
lifeTime="-1" positionX="680" positionY="400"
sizeY="160">...</transition>
    <transition id="Z8" name="Z_{8}" priority="0" startTime="0"
lifeTime="-1" positionX="820" positionY="100"
sizeY="460">...</transition>
  </transitions>
  <places>
    <place id="input" name="input" priority="0" capacity="-1"
char="addInputChar" merge="false" positionX="50" positionY="220"/>
    <place id="sinput" name="sinput" priority="0" capacity="-1"
char="addSInputChar" merge="false" positionX="50" positionY="280"/>
    <place id="l1" name="l_{1}" priority="0" capacity="-1"
char="addL1Char" merge="false" positionX="150" positionY="160"/>
   ...
  </places>
  <tokens> ... </tokens>
  <functions> ... </functions>
</gn>
```

An important clarification is that function
ObjectAnalyzeSatisfyRequirements is used as a predicate implement the
conjunction $\neg W_{1,2} \wedge W_{1,1}$.

The characteristic and predicates functions are written in JavaScript and they cover all set in the description above requirements for availability of resources, environment factors and current status of the GB object.

The data used in the simulation is taken from actual measurements made by six people who will denote by A-operator, B-operator, C-operator, D-operator, E-operator, F-operator.

The movement of the *subject* and *GBObject* tokens in the GN and update of their characteristics is shown in Fig. 2 and Fig. 3.
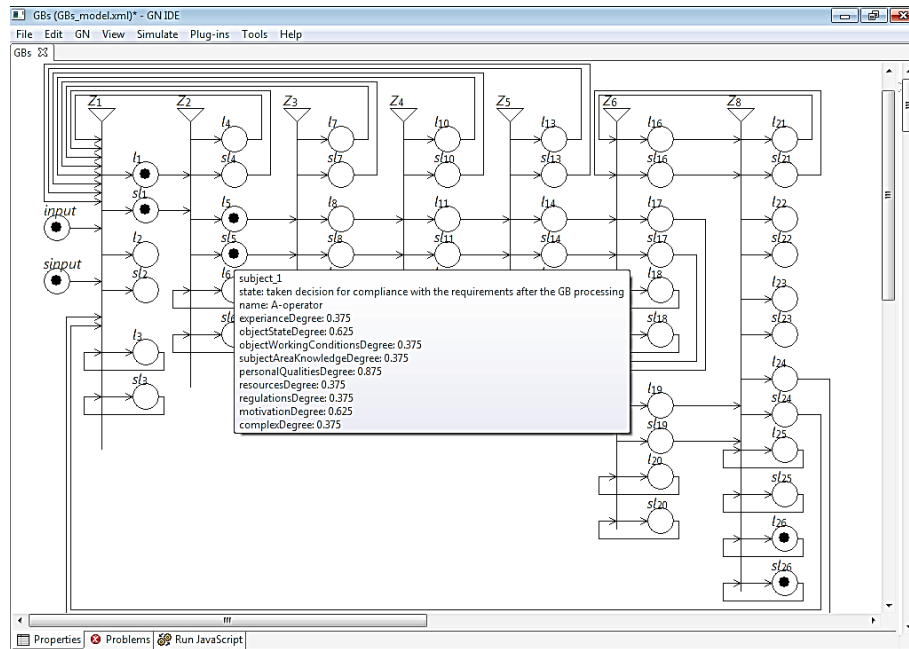
Figure 2. The movement of token *subject* and its characteristics in place sl_5.

The main goal of the simulation is to provide a relationship between the assessment of the of the different operators (subjects) and their results measurement.

The relationship between the complex evaluation of the subjects and the deviation from the average size of the GB and their measurement is shown in Fig. 4.
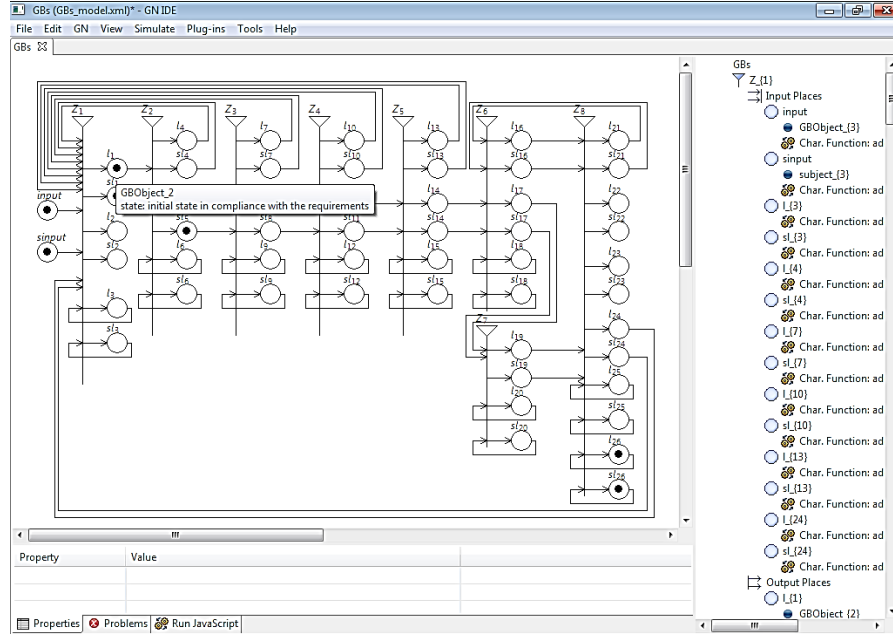
Figure 3. The movement of token *GBObject* and the value of its characteristic *state* in place l_1.

4 Conclusion

The implemented GN model shows all real stages of measuring plane-parallel stop-end length gauges. For the first time it is taken into account a subjective factor associated with the level of competence of the subject and the relationship between it and measurement results. Implemented simulation show the actual process of GB measuring in the Central Laboratory for Measuring Equipment at the Prof. Tsvetan Lazarov Institute of Defence. The data that is used is taken from a real calibration of a stop-end length gauge sized 50mm that is performed from six persons (subjects).
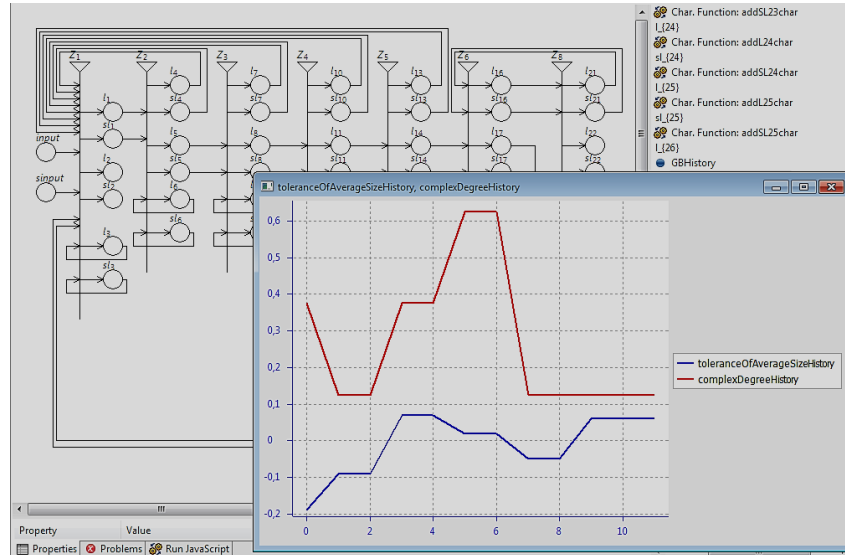
Figure 4. Graph of complex evaluation of the subjects and the GB deviation from the average size.

References

[1]   Angelova, N., M. Todorova, K. Atanassov, GN IDE: Implementation, Improvements and Algorithms, *Comptes rendus de l'Acade'mie bulgare des Sciences*, Vol. 69, 2016, No. 4, 411-420.

[2]   Andonov, V., N. Angelova. Modifications of the algorithms for transition functioning in GNs, GNCP, IFGNCP1 and IFGNCP3 when merging of tokens is permitted. *Inprecision and Uncertainty in Information Representation and Processing (P. Angelov, S. Sotirov, Eds.)*, Springer, Cham, 2016, 275-288.

[3]   EN ISO 3650:1998 – Geometrical product specifications (GPS) – Length standards – Gauge blocks.

[4]   EA-4/02 M:2013 – Evaluation of the Uncertainty of Measurement in Calibration.