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Exclusion Rule-based Systems—case study

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***Abstract*—The *exclusion rule-based system*, proposed in the paper, is an alternative method of designing a rule-based system for an expert or a control system. The starting point of the approach is the set of all possible decisions the considered system can generate. Then, on the basis of the exclusion rules, the set of decisions is limited to the ones permissible in the current state.**

A railway traffic management system case study is used in the paper to demonstrate the advantages of the new approach. To compare the exclusion rule-based systems with the decision tables both solutions are considered.

I. Introduction

ALTHOUGH rule-based systems are widely used in various kinds of computer systems, e.g. expert systems, decision support systems, monitoring and control systems, diagnostic systems etc., their encoding, analysis and design can be a time-consuming, tedious and difficult task ([1], [2], [3], [4]). Their expressive power, the scope of the potential application and very intuitive form, make them a very handy and useful mechanism. However, if more complex systems are considered, it is difficult to cope with the number of attributes or/and the number of decision rules.

Rule-based systems can be represented in various forms, e.g. decision tables, decision trees, extended tabular trees (XTT, [5]), Petri nets ([6]), etc. Decision tables seem to be the most popular form of rule-based systems presentation. Depending on the way the condition and decision entries are represented, a few kinds of decision tables can be distinguished ([7], [8], [3]). The simpler ones are decision tables with atomic values of attributes. However, encoding decision tables with the use of atomic values of attributes only is not sufficient for many real applications. On the other hand, tables with generalised decision rules ([9]) use formulae instead of atomic values of attributes. Each generalised decision rule covers a set of decision rules with atomic values of attributes (simple decision rules). Therefore, the number of generalised decision rules is significantly lower than the number of the simple ones.

In spite of this, it can be really hard to cope with the design of such a decision table if it contains a dozen or so condition attributes or/and each of them can take a few different values. It appears that it is simpler to point out one or two values of some condition attributes that disqualify some decisions, than to point out values of dozen attributes that determine a single decision.

This observation provides the basis for the approach presented in the paper. We start with the set of all possible decisions the considered system can generate. Then, instead of constructing the precondition of a decision rule that usually contains most of the condition attributes, we construct the precondition of an exclusion decision rule that usually contains a single attribute. Thus, instead of pointing out a single decision permissible in the current state, we point out a set of impermissible ones.

In most basic versions, a rule-based system consists of a single-layer set of rules and a simple inference engine. It works by selecting and executing a single rule at a time, provided that the preconditions of the rule are satisfied in the current state. Thus, such a system generates a single decision, even if there are a few suitable ones. On the other hand, when an exclusion rule-based system is used, then executing a single exclusion rule removes some impermissible decision from the set of all possible ones. After executing all exclusion rules with satisfied preconditions, the set contains all decisions permissible in the considered state.

The paper presents the idea of *exclusion rule-based systems* (shortly ExRBS). To point out the main differences between generalised decision tables and exclusion rule-based systems, we describe the two forms of rule-based systems for a railway traffic management system. The system uses a rule-based system to choose routes for trains moving through a train station.

The paper is organized as follows. The railway traffic management system is described in Section II. The generalized decision table is presented in Section III. The exclusion rule-based system is described in Section IV. The paper ends with a short summary in the final section.

II. Railway traffic management system

A description of a railway traffic management system for a real train station is discussed in this section. To present complete rule-based systems, a small train station, Czarna Tarnowska, belonging to the Polish railway line no 91 from Kraków to Medyka, has been chosen. This example seems to be suitable for the presentation of an exclusion rule-based system. However, it will be shown that the approach can also be applied to more complex systems.

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TABLE I
REQUIRED POSITION OF TURNOUTS FOR ALL POSSIBLE ROUTES

	Turnouts								
Routes	3/4	5	6	7/8	15/16	17	18	19/20	21/22
B1	+	+							
B2	–		+	o+					
B3	+	–							
B4	–		–	+	o+				
R2				o+	o+	+		+	+
R4				o+	+	–		+	+
F2W	+		+	o+					
G2W	+		–	+					
K1D					+	–		–	+
L1D					o+	+		–	+
M1D							+	+	+
N1D							–	+	+

TABLE II
RELATIONSHIPS BETWEEN ROUTES

	B1	B2	B3	B4	R2	R4	F2W	G2W	K1D	L1D	M1D	N1D
B1	–	x	x	x								xx
B2	x	–	x	x	xx		x	x				
B3	x	x	–	x								
B4	x	x	x	–	xx	xx	x	x				
R2		xx		xx	–	x		xx	x	x		
R4				xx	x	–			x	x		
F2W		x		x			–	x				
G2W		x		x	xx		x	–				
K1D					x	x			–	x	x	x
L1D					x	x			x	–	x	x
M1D									x	x	–	x
N1D	xx								x	x	x	–

The considered system is used to ensure safe riding of trains through the station. It collects some information about current railway traffic and uses a rule-based system to choose routes for trains.

The topology of the train station with original signs is shown in Fig. 1. The letters A, B, D, etc. stand for color light signals, the symbols Z3, Z4, Z5, etc. stand for turnouts and JTA, JTB, JT1, etc. stand for track segments. Some simplifications have been introduced to reduce the size of the model. We are not interested in controlling the local shunts so the track segment JT6 will not be considered. We assume that the light signals display only two signals: *stop* and *way free*. Moreover, outside the station the trains can ride using the right track only.

A train can ride through the station only if a suitable route has been prepared for it i.e., suitable track segments must be free, we have to set turnouts and light signals and to guarantee exclusive rights to these elements for the train. Required position of turnouts for all possible routes are shown in Table I, where the used symbols stand for:

- + closed turnout (the straight route);
- – open turnout (the diverging route);
- o+ closed turnout (for safety reasons).

For example, the symbol B4 stands for the input route from the light signal B to the track no. 4. The symbol F2W stands for the output route from the track no. 2 (from the light signal F) to the right (to Wola Rzędzińska), etc. The route B4 can be used by a train only if: turnouts 7, 8, 15, 16 are closed, turnouts 3, 4, 6 are open, and the track segments JTB, JT4, JZ4/6 (a segment between turnouts 4 and 6), JZ7 (diagonal segment leading to the turnout 7) and JZ16 are free.

Some routes cannot be set at the same time because of different position of turnouts or for safety reasons. Mutually exclusive routes are presented in Table. II, where the used symbols stand for:

- x – mutually exclusive (different position of turnouts);
- xx – mutually exclusive (safety reasons).

The system is expected to choose suitable routes for moving trains. It should take under consideration that some trains should stop at the platform, while others are only moving through the station and two routes (an input and an output one) should be prepared for them. In such a case, if it is not possible to prepare two routes, only an input one should be prepared.

III. DECISION TABLE

Decision tables are a precise and compact form of rule-based systems presentation. They vary in the way the condition and decision entries are represented. The entries can take the form of simple true/false values, atomic values of different types, non-atomic values or even fuzzy logic formulas [3].

To construct a decision table, we draw a column for each condition (or stimulus) that will be used in the process of taking a decision. Next, we add columns for each action (or response) that we may want the system to perform (or generate). Then, for every possible combination of values of those conditions a row should be drawn. We fill cells so as to reflect which actions should be performed for each combination of conditions. Each such a row is called a *decision rule*.

A kind of decision tables with generalized rules is used in this section [9]. Systems with non-atomic values are considered since their expressive power is much higher than the one of classical attributive decision tables. Each cell of such a decision table should contain a formula which evaluates to a boolean value for condition attributes, and to a single value (that belongs to the corresponding domain) for decision attributes.

Let us focus on the railway traffic management system. The rule-based system is to be used to determine which routes should be prepared depending on the data collected from sensors. The decision table contains 20 condition and 2 decision attributes. The condition attributes stand for information about:

- current position of the train (attribute JT) – before the light signal B, F, G, etc.;
- type of the train (attribute TT) – only moves through the station (1) or must stop at the platform (2);
- current status of track segments (attributes JT1, JT2, JT3, JT4, JOA, JOP) – a segment is free (0) or it is taken (1);
- already prepared routes (attributes B1, B2, B3, etc.) – a route is already set (1) or not (0).

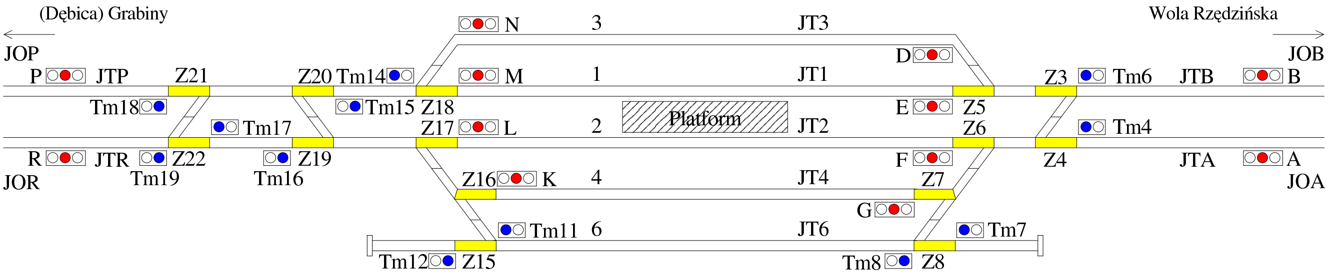

Fig. 1. Czarna Tarnowska – topology of the train station

The decision attributes In and Out represent the input and output routes (that will be prepared for the train) respectively. Domains for these attributes are defined as follows:
$D_{\mathrm{JT}} = \{\mathrm{b}, \mathrm{f}, \mathrm{g}, \mathrm{k}, \mathrm{l}, \mathrm{m}, \mathrm{n}, \mathrm{r}\}$,
$D_{\mathrm{TT}} = \{1, 2\}$,
$D_{\mathrm{JT1}} = D_{\mathrm{JT2}} = D_{\mathrm{JT3}} = D_{\mathrm{JT4}} = D_{\mathrm{JOA}} = D_{\mathrm{JOP}} = \{0, 1\}$,
$D_{\mathrm{B1}} = D_{\mathrm{B2}} = \ldots = D_{\mathrm{N1D}} = \{0, 1\}$,
$D_{\mathrm{In}} = \{\mathrm{b1}, \mathrm{b2}, \mathrm{b3}, \mathrm{b4}, \mathrm{r2}, \mathrm{r4}, \mathrm{none}\}$,
$D_{\mathrm{Out}} = \{\mathrm{f2w}, \mathrm{g2w}, \mathrm{k1d}, \mathrm{l1d}, \mathrm{m1d}, \mathrm{n1d}, \mathrm{none}\}$.

The decision table is presented in table III. Each row represents one decision rule. Let us consider the first rule. It can be represented as follows:

$$
\begin{aligned}
&(\mathrm{JT} = b) \wedge (\mathrm{TT} = 1) \wedge (\mathrm{JT1} = 0) \wedge (\mathrm{JOP} = 0) \\
&\wedge\ (\mathrm{B1} = 0) \wedge (\mathrm{B2} = 0) \wedge (\mathrm{B3} = 0) \wedge (\mathrm{B4} = 0) \\
&\wedge\ (\mathrm{K1D} = 0) \wedge (\mathrm{L1D} = 0) \wedge (\mathrm{M1D} = 0) \\
&\wedge\ (\mathrm{N1D} = 0) \Rightarrow (\mathrm{b1}, \mathrm{m1d})
\end{aligned} \tag{1}
$$

It means that if:

- a train of type 1 is approaching the light signals B (or stands before it), and
- track segments JT1 and JOP are empty, and
- routes B1, B2, B3, B4, K1D, L1D, M1D and N1D are not set,

then routes b1 and m1d should be prepared for the train. It is also worth mentioning that in the considered state other decision are also possible. For example, the following pairs of routes can be used: (b2, l1d), (b3, n1d) or (b4, k1d).

If a row contains empty cells, it means that the values of some attributes are not important for the rule. For example, when rule R1 is considered, it makes no difference what the value of attribute JT2 is.

A. *Adder DT Designer*

The presented rule-based system has been used in an RTCP-net (Petri net) model of the railway traffic management system. A description of the model can be found in [10]. The decision table has been designed using *Adder DT Designer* ([9]). The tool supports design and analysis of generalised decision tables. It supports three types of attributes' domains: integer, boolean and enumerated data type. The verification stage is included into the design process. At any time, during the design stage, users can check whether a decision table is complete, consistent (deterministic) or if it contains some dependent rules.

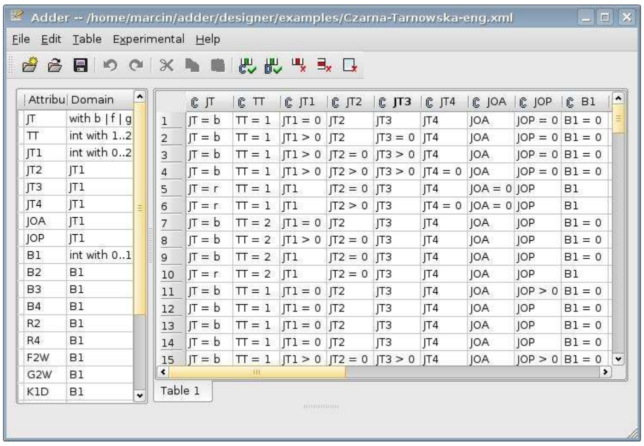

Fig. 2. Adder DT Designer

An example of *Adder DT Designer* session is shown in Fig. 2. The tool is a free software covered by the GNU Library General Public License. It is being implemented in the GNU/Linux environment by the use of the Qt Open Source Edition. More information about *Adder DT Designer* and the current version of the tool can be found at *http://fm.ia.agh.edu.pl*.

IV. Exclusion Rule-Based System

To apply the rule R1 considered in the previous section, it is necessary to check twelve conditions. Further to that, to apply any of the rules presented in Table II, at least seven conditions must be checked. Let us consider Table II that presents mutually exclusive routes. If route B1 is already set, then it cannot be set once again at the same time and also none of routes B2, B3, B4 and N1D can be set.

Suppose the current state is defined as follows: JT $= b$, TT $= 1$, $B1 = 1$ and all other attributes are equal to zero. Let $\mathcal{D}_0$ denote the set of all possible decisions:

$$
\begin{aligned}
\mathcal{D}_0 = \{&(\mathrm{b1}, \mathrm{m1d}), (\mathrm{b2}, \mathrm{l1d}), (\mathrm{b3}, \mathrm{n1d}), (\mathrm{b4}, \mathrm{k1d}), \\
&(\mathrm{r2}, \mathrm{f2w}), (\mathrm{r4}, \mathrm{g2w}), (\mathrm{b1}, \mathrm{none}), (\mathrm{b2}, \mathrm{none}), \\
&(\mathrm{b3}, \mathrm{none}), (\mathrm{b4}, \mathrm{none}), (\mathrm{r2}, \mathrm{none}), (\mathrm{r4}, \mathrm{none}), \\
&(\mathrm{none}, \mathrm{k1d}), (\mathrm{none}, \mathrm{l1d}), (\mathrm{none}, \mathrm{m1d}), \\
&(\mathrm{none}, \mathrm{n1d}), (\mathrm{none}, \mathrm{f2w}), (\mathrm{none}, \mathrm{g2w}), \}
\end{aligned} \tag{2}
$$

If attribute $B1$ is equal to 1, then the following decisions are impermissible in the considered state: $(\mathrm{b1}, \mathrm{m1d})$, $(\mathrm{b2}, \mathrm{l1d})$,

TABLE III
DECISION TABLE

	JT	TT	JT1	JT2	JT3	JT4	JOA	JOP	B1	B2	B3	B4	R2	R4	F2W	G2W	K1D	L1D	M1D	N1D	In	Out
R1	JT = b	TT = 1	JT1 = 0					JOP = 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 0	M1D = 0	N1D = 0	b1	m1d
R2	JT = b	TT = 1	JT1 > 0		JT3 = 0			JOP = 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 0	M1D = 0	N1D = 0	b3	n1d
R3	JT = b	TT = 1	JT1 > 0	JT2 = 0	JT3 > 0			JOP = 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 0	N1D = 0	b2	l1d
R4	JT = b	TT = 1	JT1 > 0	JT2 > 0	JT3 > 0	JT4 = 0		JOP = 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 0	N1D = 0	b4	k1d
R5	JT = r	TT = 1		JT2 = 0			JOA = 0			B2 = 0		B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 0			r2	f2w
R6	JT = r	TT = 1		JT2 > 0		JT4 = 0	JOA = 0			B2 = 0		B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 0			r4	g2w
R7	JT = b	TT = 2	JT1 = 0						B1 = 0	B2 = 0	B3 = 0	B4 = 0								N1D = 0	b1	none
R8	JT = b	TT = 2	JT1 > 0	JT2 = 0					B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0					b2	none
R9	JT = b	TT = 2		JT2 = 0					B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 0	N1D = 1	b2	none
R10	JT = r	TT = 2		JT2 = 0						B2 = 0		B4 = 0	R2 = 0	R4 = 0		G2W = 0	K1D = 0	L1D = 0			r2	none
R11	JT = b	TT = 1	JT1 = 0					JOP > 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0								N1D = 0	b1	none
R12	JT = b	TT = 1	JT1 = 0						B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 1	L1D = 0	M1D = 0	N1D = 0	b1	none
R13	JT = b	TT = 1	JT1 = 0						B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 1	M1D = 0	N1D = 0	b1	none
R14	JT = b	TT = 1	JT1 = 0						B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 0	M1D = 1	N1D = 0	b1	none
R15	JT = b	TT = 1	JT1 > 0	JT2 = 0	JT3 > 0			JOP > 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0					b2	none
R16	JT = b	TT = 1	JT1 > 0	JT2 = 0	JT3 > 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 1	F2W = 0	G2W = 0	K1D = 0	L1D = 0			b2	none
R17	JT = b	TT = 1	JT1 > 0	JT2 = 0	JT3 > 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0	K1D = 1	L1D = 0	M1D = 0	N1D = 0	b2	none
R18	JT = b	TT = 1	JT1 > 0	JT2 = 0	JT3 > 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0	K1D = 0	L1D = 1	M1D = 0	N1D = 0	b2	none
R19	JT = b	TT = 1	JT1 > 0	JT2 = 0	JT3 > 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 1	N1D = 0	b2	none
R20	JT = b	TT = 1		JT2 = 0	JT3 > 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0		F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 0	N1D = 1	b2	none
R21	JT = b	TT = 1	JT1 > 0		JT3 = 0			JOP > 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0									b3	none
R22	JT = b	TT = 1	JT1 > 0		JT3 = 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 1	L1D = 0	M1D = 0	N1D = 0	b3	none
R23	JT = b	TT = 1	JT1 > 0		JT3 = 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 1	M1D = 0	N1D = 0	b3	none
R24	JT = b	TT = 1	JT1 > 0		JT3 = 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 0	M1D = 1	N1D = 0	b3	none
R25	JT = b	TT = 1			JT3 = 0				B1 = 0	B2 = 0	B3 = 0	B4 = 0					K1D = 0	L1D = 0	M1D = 0	N1D = 1	b3	none
R26	JT = b	TT = 1	JT1 > 0	JT2 > 0	JT3 > 0	JT4 = 0		JOP > 0	B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0					b4	none
R27	JT = b	TT = 1	JT1 > 0	JT2 > 0	JT3 > 0	JT4 = 0			B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 1	L1D = 0	M1D = 0	N1D = 0	b4	none
R28	JT = b	TT = 1	JT1 > 0	JT2 > 0	JT3 > 0	JT4 = 0			B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 1	M1D = 0	N1D = 0	b4	none
R29	JT = b	TT = 1	JT1 > 0	JT2 > 0	JT3 > 0	JT4 = 0			B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 1	N1D = 0	b4	none
R30	JT = b	TT = 1		JT2 > 0	JT3 > 0	JT4 = 0			B1 = 0	B2 = 0	B3 = 0	B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 0	K1D = 0	L1D = 0	M1D = 0	N1D = 1	b4	none
R31	JT = r	TT = 1		JT2 = 0			JOA > 0			B2 = 0		B4 = 0	R2 = 0	R4 = 0		G2W = 0	K1D = 0	L1D = 0			r2	none
R32	JT = r	TT = 1		JT2 = 0						B2 = 0		B4 = 0	R2 = 0	R4 = 0	F2W = 1	G2W = 0	K1D = 0	L1D = 0			r2	none
R33	JT = r	TT = 1		JT2 > 0		JT4 = 0	JOA > 0					B4 = 0	R2 = 0	R4 = 0			K1D = 0	L1D = 0			r4	none
R34	JT = r	TT = 1				JT4 = 0			B1 = 0	B2 = 1	B3 = 0	B4 = 0	R2 = 0	R4 = 0			K1D = 0	L1D = 0			r4	none
R35	JT = r	TT = 1		JT2 > 0		JT4 = 0						B4 = 0	R2 = 0	R4 = 0	F2W = 1	G2W = 0	K1D = 0	L1D = 0			r4	none
R36	JT = r	TT = 1				JT4 = 0						B4 = 0	R2 = 0	R4 = 0	F2W = 0	G2W = 1	K1D = 0	L1D = 0			r4	none
R37	JT = k	TT = 1				JT4 > 0		JOP = 0					R2 = 0	R4 = 0			K1D = 0	L1D = 0	M1D = 0	N1D = 0	none	k1d
R38	JT = l			JT2 > 0				JOP = 0					R2 = 0	R4 = 0			K1D = 0	L1D = 0	M1D = 0	N1D = 0	none	l1d
R39	JT = m		JT1 > 0					JOP = 0									K1D = 0	L1D = 0	M1D = 0	N1D = 0	none	m1d
R40	JT = n	TT = 1			JT3 > 0			JOP = 0	B1 = 0								K1D = 0	L1D = 0	M1D = 0	N1D = 0	none	n1d
R41	JT = f			JT2 > 0			JOA = 0			B2 = 0		B4 = 0			F2W = 0	G2W = 0					none	f2w
R42	JT = g	TT = 1				JT4 > 0	JOA = 0			B2 = 0		B4 = 0	R2 = 0		F2W = 0	G2W = 0					none	g2w

E_1: $(\mathrm{B1} = 1) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (*, \mathrm{n1d})\}$
E_2: $(\mathrm{B2} = 1) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w})\}$
E_3: $(\mathrm{B3} = 1) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *)\}$
E_4: $(\mathrm{B4} = 1) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w})\}$
E_5: $(\mathrm{R2} = 1) \Rightarrow \{(\mathrm{b2}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{g2w}), (*, \mathrm{k1d}), (*, \mathrm{l1d})\}$
E_6: $(\mathrm{R4} = 1) \Rightarrow \{(\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{k1d}), (*, \mathrm{l1d})\}$
E_7: $(\mathrm{F2W} = 1) \Rightarrow \{(\mathrm{b2}, *), (\mathrm{b4}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w})\}$
E_8: $(\mathrm{G2W} = 1) \Rightarrow \{(\mathrm{b2}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w})\}$
E_9: $(\mathrm{K1D} = 1) \Rightarrow \{(\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{10}: $(\mathrm{L1D} = 1) \Rightarrow \{(\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{11}: $(\mathrm{M1D} = 1) \Rightarrow \{(*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{12}: $(\mathrm{N1D} = 1) \Rightarrow \{(\mathrm{b1}, *), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{13}: $(\mathrm{JT} = b) \wedge (\mathrm{JT1} > 0) \Rightarrow \{(\mathrm{b1}, *)\}$
E_{14}: $(\mathrm{JT} = b) \wedge (\mathrm{JT2} > 0) \Rightarrow \{(\mathrm{b2}, *)\}$
E_{15}: $(\mathrm{JT} = b) \wedge (\mathrm{JT3} > 0) \Rightarrow \{(\mathrm{b3}, *)\}$
E_{16}: $(\mathrm{JT} = b) \wedge (\mathrm{JT4} > 0) \Rightarrow \{(\mathrm{b4}, *)\}$
E_{17}: $(\mathrm{JT} = r) \wedge (\mathrm{JT2} > 0) \Rightarrow \{(\mathrm{r2}, *)\}$
E_{18}: $(\mathrm{JT} = r) \wedge (\mathrm{JT4} > 0) \Rightarrow \{(\mathrm{r4}, *)\}$
E_{19}: $(\mathrm{JT} = b) \wedge (\mathrm{TT} = 2) \Rightarrow \{(\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{b1}, \mathrm{m1d}), (\mathrm{b2}, \mathrm{l1d})\}$
E_{20}: $(\mathrm{JT} = r) \wedge (\mathrm{TT} = 2) \Rightarrow \{(\mathrm{r4}, *), (\mathrm{r2}, \mathrm{f2w})\}$
E_{21}: $(\mathrm{JOA} > 0) \Rightarrow \{(*, \mathrm{f2w}), (*, \mathrm{g2w})\}$
E_{22}: $(\mathrm{JOP} > 0) \Rightarrow \{(*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{23}: $(\mathrm{JT} = b) \Rightarrow \{(\mathrm{r2}, *), (\mathrm{r4}, *), (\mathrm{none}, *)\}$
E_{24}: $(\mathrm{JT} = r) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{none}, *)\}$
E_{25}: $(\mathrm{JT} = k) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{26}: $(\mathrm{JT} = l) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w}), (*, \mathrm{k1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{27}: $(\mathrm{JT} = m) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w}), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{n1d})\}$
E_{28}: $(\mathrm{JT} = n) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{f2w}), (*, \mathrm{g2w}), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d})\}$
E_{29}: $(\mathrm{JT} = f) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{g2w}), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$
E_{30}: $(\mathrm{JT} = g) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (\mathrm{r2}, *), (\mathrm{r4}, *), (*, \mathrm{f2w}), (*, \mathrm{k1d}), (*, \mathrm{l1d}), (*, \mathrm{m1d}), (*, \mathrm{n1d})\}$

Fig. 3. Exclusion rule-based system

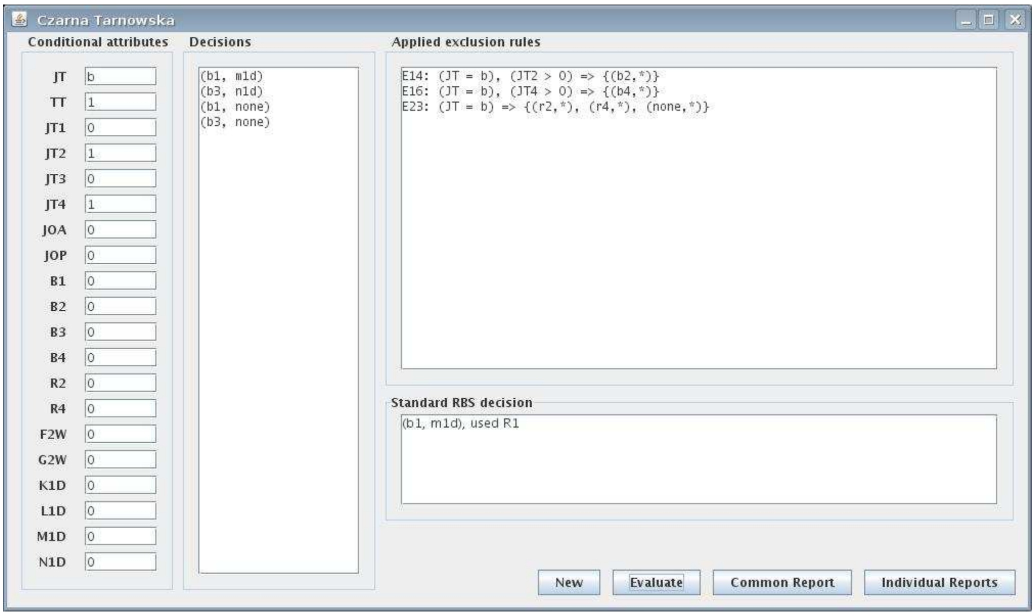

Fig. 4. Comparison of rule-based systems

$(\mathrm{b3}, \mathrm{n1d})$, $(\mathrm{b4}, \mathrm{k1d})$, $(\mathrm{b1}, \mathrm{none})$, $(\mathrm{b2}, \mathrm{none})$, $(\mathrm{b3}, \mathrm{none})$, $(\mathrm{b4}, \mathrm{none})$, $(\mathrm{none}, \mathrm{n1d})$.

For simplicity, the asterisk $(*)$ will be used to denote any value the corresponding entry can take. Thus, the first exclusion rule $E1$ takes the following form:

$$E_1\colon (\mathrm{B1} = 1) \Rightarrow \{(\mathrm{b1}, *), (\mathrm{b2}, *), (\mathrm{b3}, *), (\mathrm{b4}, *), (*, \mathrm{n1d})\} \tag{3}$$

Each row of Table II generates an exclusion decision rule. Thus, the constructed exclusion rule-based system will also contain next eleven rules (see Fig. 3, rules from E_2 to E_{12}).

Let us focus on the train station topology (see Fig. 1). If a train position (attribute TJ) is equal to b and track segment JT1 is taken by another train, then any route leading through the track segment cannot be taken under consideration. Thus, we have the following exclusion rule:

$$E_{13}\colon (\mathrm{JT} = b) \wedge (\mathrm{JT1} > 0) \Rightarrow \{(\mathrm{b1}, *)\} \tag{4}$$

Similarly, we can investigate situations when one of track segments JT2, JT3, JT4 is busy, or a train position is equal to r and track segment JT2 or JT4 is busy – see rules from E_{14} to E_{19}.

If a train type (attribute TT) is equal to 2, then it should stop at the platform. In such a case only an input route must be prepared and routes leading through track segments JT3 and JT4 cannot be taken under consideration – see rules E_{20} and E_{21}. Moreover, an output route can be prepared only if the corresponding output track segment is free (track segments JOA and JOP) – see rules E_{22} and E_{23}.

The last group of exclusion rules corresponds to the direction of trains moving. If a train position is equal to b, then the train moves from 'east' to 'west' and first of all an input route for the train must be prepared. Thus, any decisions with the input route equal to *none* or with routes leading to east are impermissible in such a situation. Therefore, the ExRBS must contain the following exclusion rule:

$$E_{23}\colon (\mathrm{JT} = b) \Rightarrow \{(\mathrm{r2}, *), (\mathrm{r4}, *), (\mathrm{none}, *)\} \tag{5}$$

In a similar way, the other seven train positions can be investigated. Finally, the ExRBS must be extended with seven exclusion rules (see Fig. 3, rules from E_{23} to E_{30}).

Executing a single exclusion rule removes some impermissible decisions from the set of all possible ones. The set of decision excluded by an exclusion rule will be denoted by $\mathcal{E}(E_i)$. Hence, for example, the set $\mathcal{E}(E_1)$ contains the following elements:

$$\begin{aligned}\mathcal{E}(E_1) = \{&(\mathrm{b1}, \mathrm{m1d}), (\mathrm{b2}, \mathrm{l1d}), (\mathrm{b3}, \mathrm{n1d}),\\ &(\mathrm{b4}, \mathrm{k1d}), (\mathrm{b1}, \mathrm{none}), (\mathrm{b2}, \mathrm{none}),\\ &(\mathrm{b3}, \mathrm{none}), (\mathrm{b4}, \mathrm{none}), (\mathrm{none}, \mathrm{n1d})\}\end{aligned} \tag{6}$$

Let $\mathcal{D}_i$ denote the set of permissible decisions after executing the rule E_i. The following equality holds:

$$\mathcal{D}_{i+1} = \mathcal{D}_i - \mathcal{E}(E_{i+1}) \tag{7}$$

After executing all exclusion rules with satisfied preconditions, the set contains all decisions permissible in the considered state.

For the state considered in this section, rules $E1$ and $E23$ can be applied. The final set of permissible decisions $\mathcal{D}$ is empty. It means that at the moment no route for the train can be prepared. Another example—a state and decisions generated by the decision table and the exclusion rule-based system—is presented in Fig. 4.

The decision table presented in the previous section is complete and deterministic. It means that if it is possible to generate a decision for any acceptable state, then only one decision is generated. To compare the two presented rule-based systems, a Java software has been implemented and decisions generated by the systems for any acceptable state have been compared.[1] For any state the ExRBS generates at least the same decision as the decision table (for many states ExRBS generates more than one possibility).

V. Conclusion

The idea of exclusion rule-based systems has been given in this paper, and a comparison has been made between decision tables and exclusion rule-based systems. The latter ones can be treated as an alternative method of designing rule-based systems. The presented approach has been illustrated by the use of an example of a railway traffic management system. In this case, ExRBS is significantly more readable and adaptable. In contrast to decision tables, an ExRBS for a train station with different topology and size can be easily constructed in a very similar way. Moreover, the exclusion rule-based system contains less decision rules then the corresponding decision table and the design of the ExRBS was significantly less time-consuming.

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[1]For more details see `http://fm.ia.agh.edu.pl`