UNIVERSIDADE FEDERAL DO CEARÁ

CENTRO DE CIÊNCIAS

DEPARTAMENTO DE COMPUTAÇÃO

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIA DA COMPUTAÇÃO

RENAN PEREIRA DE FIGUEIREDO

AUTOMATED VERIFICATION OF CARE PATHWAYS USING CONSTRAINT PROGRAMMING

FORTALEZA

2019

RENAN PEREIRA DE FIGUEIREDO

AUTOMATED VERIFICATION OF CARE PATHWAYS USING CONSTRAINT PROGRAMMING

Dissertação apresentada ao Curso de do Programa de Pós-Graduação em Ciência da Computação do Centro de Ciências da Universidade Federal do Ceará, como requisito parcial à obtenção do título de mestre em Ciência da Computação. Área de Concentração: Engenharia de Software

Orientador: Prof. Dr. João Bosco Ferreira Filho

FORTALEZA

2019

Dados Internacionais de Catalogação na Publicação
Universidade Federal do Ceará
Biblioteca Universitária
Gerada automaticamente pelo módulo Catalog, mediante os dados fornecidos pelo(a) autor(a)

F492a Figueiredo, Renan Pereira de.
Automated Verification of Care Pathways Using Constraint Programming / Renan Pereira de Figueiredo. – 2019.
97 f. : il. color.

Dissertação (mestrado) – Universidade Federal do Ceará, Centro de Ciências, Programa de Pós-Graduação em Ciência da Computação, Fortaleza, 2019.
Orientação: Prof. Dr. João Bosco Ferreira Filho.

1. Clinical Pathway. 2. Constraint Programming. 3. Data-Dependent Transition System. 4. DSL. 5. Satisfiability Problems. I. Título.

CDD 005

RENAN PEREIRA DE FIGUEIREDO

AUTOMATED VERIFICATION OF CARE PATHWAYS USING CONSTRAINT PROGRAMMING

Dissertação apresentada ao Curso de do Programa de Pós-Graduação em Ciência da Computação do Centro de Ciências da Universidade Federal do Ceará, como requisito parcial à obtenção do título de mestre em Ciência da Computação. Área de Concentração: Engenharia de Software

Aprovada em: 07 de Outubro de 2019

BANCA EXAMINADORA

Prof. Dr. João Bosco Ferreira Filho (Orientador)
Universidade Federal do Ceará (UFC)

Prof. Dr. Lincoln Souza Rocha
Universidade Federal do Ceará (UFC)

Prof. Dr. João Fernando Lima Alcântara
Universidade Federal do Ceará (UFC)

Prof. Dr. Paulo Henrique Mendes Maia
Universidade Estadual do Ceará (UECE)

To my family and friends for believing in me and supporting my choices. Mother, her care and dedication was what gave me hope to follow. Father, his presence meant security and makes me sure I'm not alone on this journey.

ACKNOWLEDGEMENTS

To Prof. Dr. João Bosco Ferreira filho for guiding me in my master dissertation.

To Professors Dr. Lincoln Souza Rocha and Dr. João Fernando Lima Alcântara for helping me with suggestions for improvements and corrections in my master dissertation.

To Computer Science Master student, Douglas Lopes Dias, for helping me with the initial implementation of the algorithms, as well as reviewing my papers and dissertation. And to Iago Avelino Trojano, Computer Science Master student, for giving in the pathways dataset already suitable for the verification performed in my work and for helping me in my doubts about the care pathway structure.

To my parents who always supported me and motivated me to dedicate myself to my studies, and understood my absence in family moments.

To National Scientific and Technological Development Council (CNPq) for funding Masters research via scholarship.

To IntMed Software company for providing the care pathways we analyzed in this work.

To doctors from Hapvida's hospitals for clarifying questions regarding the pathways used in the hospitals.

“Experience is not what happens to you; it’s what you do with what happens to you.”

(Aldous Huxley)

ABSTRACT

Clinical Pathways are used to standardize medical treatments. Specialists define these pathways using process-like notations that can ultimately be translated to formally defined languages. Bad construction of modeled care pathways can lead to satisfiability problems during the pathway execution. These problems can ultimately result in medical errors and need to be checked as formally as possible. Therefore, this study proposes a set of algorithms using a free open-source library dedicated to constraint programming allied with a DSL to encode and verify care pathways, checking four possible problems: states in deadlock, non-determinism, inaccessible steps and transitions with logically equivalent guard conditions. We then test our algorithms in 113 real care pathways used both in hospitals and surgeries. Using our algorithms, we were able to find 295 problems taking less than 1 second to complete the verification on most pathways.

Keywords: Clinical pathway. Constraint programming. Data-dependent transition system. DSL. Satisfiability problems.

RESUMO

Protocolos clínicos são usados para padronizar tratamentos médicos. Os especialistas definem esses protocolos usando notações de processos, que podem ser traduzidas para linguagens formalmente definidas. A má construção desses protocolos clínicos modelados pode ocasionar em problemas de satisfatibilidade durante a execução do protocolo. Esses problemas podem resultar em erros médicos e precisam ser verificados o mais formalmente possível. Portanto, este estudo propõe um conjunto de algoritmos, utilizando uma biblioteca de código aberto gratuita dedicada à programação de restrições aliada a uma DSL para codificar e verificar os protocolos clínicos, verificando quatro possíveis problemas: estados em deadlock, não determinismo, passos inacessíveis e transições com condições de guarda logicamente equivalentes. Em seguida, testamos nossos algoritmos em um conjunto com 113 protocolos clpínicos reais usados em hospitais e cirurgias. Usando nossos algoritmos, conseguimos encontrar 295 problemas, sendo necessário menos de 1 segundo para concluir a verificação na maioria dos protocolos.

Palavras-chave: Protocolo clínico. Programação por restrição. Sistema de transição dependente de dados. DSL. Problemas de satisfatibilidade.

FIGURES LIST

Figure 1 – Flowchart of a general data-dependent transition system. 19
Figure 2 – Flowchart of meningitis care pathway. 21
Figure 3 – Flowchart of an abdominal pain care pathway fragment. 22
Figure 4 – Flowcharts of generic examples of potential problems 26
Figure 5 – Abstract Syntax of the DSL. 28
Figure 6 – Flowchart of simple pathway representation. 32
Figure 7 – Graph of relation of execution time by number of nodes. 44
Figure 8 – Flowchart of a Earache Care Pathway fragment. 45
Figure 9 – Flowchart of Deep Vein Thrombosis Care Pathway fragment. 47
Figure 10 – Flowchart of UTI in Pregnant Women Care Pathway. 48
Figure 11 – Flowchart of Low Back Pain Care Pathway fragment. 50
Figure 12 – Flowchart of Exposed Fracture Care Pathway 50
Figure 13 – Flowchart of Dyslipidemia Care Pathway fragment 51

LIST OF TABLES

Table 1 – Logical representation of Figure 6 32
Table 2 – Constraints for the Operations 35
Table 3 – Care pathways dataset. 42
Table 4 – The pathways and the found problems. 42
Table 5 – Pathway complexity level. 43
Table 6 – Deadlock algorithm evaluation. 45
Table 7 – Non-determinism algorithm evaluation. 46
Table 8 – Inaccessible steps algorithm evaluation. 47
Table 9 – Equivalent transitions algorithm evaluation. 49
Table 10 – Features used in the works. 53
Table 11 – Care Pathways Dataset: continued 62
Table 12 – Care Pathways Dataset: continued 63
Table 13 – Care Pathways Dataset: conclusion 64
Table 14 – The pathways and the found problems: continued 65
Table 15 – The pathways and the found problems: continued 66
Table 16 – The pathways and the found problems: conclusion 67
Table 17 – Deadlock Algorithm Evaluation: continued 68
Table 18 – Deadlock Algorithm Evaluation: continued 69
Table 19 – Deadlock Algorithm Evaluation: conclusion 70
Table 20 – Non-Determinism Algorithm Evaluation: continued 71
Table 21 – Non-Determinism Algorithm Evaluation: continued 72
Table 22 – Non-Determinism Algorithm Evaluation: conclusion 73
Table 23 – Inaccessible Step Algorithm Evaluation: continued 74
Table 24 – Inaccessible Step Algorithm Evaluation: continued 75
Table 25 – Inaccessible Step Algorithm Evaluation: conclusion 76
Table 26 – Equivalent Transitions Algorithm Evaluation: continued 77
Table 27 – Equivalent Transitions Algorithm Evaluation: continued 78
Table 28 – Equivalent Transitions Algorithm Evaluation: conclusion 79

ABBREVIATIONS AND ACRONYMS LIST

CP	Constraint Programming
DSL	Domain Specific Language
DSML	Domain-Specific Modeling Languages
MDE	Model-Driven Engineering
TS	Transition Systems

LIST OF SYMBOLS

Act	Set of actions
AP	Set of atomic propositions
g	A guard condition
I	Set of initial states
L	Labeling function
O	Set of operands
S	Set of states
s	A state
T	Set of transitions
T_{in}	Set of input transitions
T_{out}	Set of output transitions
t	A transition
Var	Set of variables
α	An action
$\rightarrow$	A transition relation

CONTENTS

1	**INTRODUCTION**	15
1.1	**Goals**	17
2	**BACKGROUND AND MOTIVATION**	18
2.1	**Transition System Concept**	18
2.2	**Care Pathway Structure**	20
2.3	**Pathway Execution**	22
2.4	**Possible Problems in a Clinical Pathway**	25
2.5	**Model-driven engineering Approach for Care Pathways**	27
2.6	**Constraint programming Solver**	28
3	**APPROACH**	31
3.1	**Logical Structure**	31
3.2	**Running Example - Checking Problems at Meningitis Pathway**	32
3.3	**Algorithms**	33
3.3.1	***Transform Transitions to BoolVars***	34
3.3.2	***Finding deadlock***	36
3.3.3	***Finding non-determinism***	37
3.3.4	***Finding Inaccessible Steps***	37
3.3.5	***Finding Logically Equivalent Sequences***	38
4	**EVALUATION**	41
4.1	**Pathways Dataset**	41
4.2	**Results and Findings**	41
4.2.1	***Deadlock Evaluation***	44
4.2.2	***Non-Determinism Evaluation***	46
4.2.3	***Inaccessible Steps Evaluation***	47
4.2.4	***Equivalent Transitions Evaluation***	48
4.2.5	***General Examples***	49
5	**RELATED WORK**	52
6	**CONCLUSION**	55
	REFERENCES	56
	GLOSSARY	61
	APPENDIX A – CARE PATHWAYS DATASET	62

APPENDIX B – CARE PATHWAYS AND THE FOUND PROBLEMS 65
APPENDIX C – DEADLOCK EVALUATION 68
APPENDIX D – NON-DETERMINISM EVALUATION 71
APPENDIX E – INACCESSIBLE STEP EVALUATION 74
APPENDIX F – EQUIVALENT TRANSITIONS EVALUATION . . . 77
APPENDIX G – DEADLOCK FOUND 80
APPENDIX H – NON-DETERMINISM FOUND 91
APPENDIX I – INACCESSIBLE STEPS FOUND 98

1 INTRODUCTION

The development of new technological resources aimed at the health sector is reshaping medical practice and expanding the range of possible treatments for a given pathology (MV, 2016). The behavioral variability, coupled with the exponential growth of the volume of scientific information, and the advent of evidence-based medicine (DJULBEGOVIC; GUYATT, 2017; COSGROVE *et al.*, 2018), have driven health care stakeholders to search for standardization, provided by a well-defined care pathway.

These care pathways use evidence-based research unifying the best evidence of research with clinical experience, patient values and preferences to determine the right treatment at the right time and in the right way (LOPEZ; RAMIREZ, 2017). Among their many benefits, care pathways reduce possible errors of diagnosis and improve the quality of service (CABALLERO *et al.*, 2017; SHI *et al.*, 2008; COSGROVE *et al.*, 2018). Furthermore, its design and implementation help reduce health costs that represent about 5.99% of the world's annual gross domestic product (PRODEL, 2017). These cost savings can be mainly observed through reductions in treatment variations and over-testing (EVANS-LACKO *et al.*, 2010). In a study conducted by Elis, et al. it is analyzed the impact of a change to the orientation of the mCRC (metastatic colorectal cancer), demonstrating that the pathways can be used to assist oncological practices in reducing costs by considering regimen cost information (ELLIS *et al.*, 2017).

One way of implementing care pathways is to mirror the structure of industrial and business processes. These process-based guidelines assist health professionals with decision making when treating patients, using best practices, facilitating communication and sequencing the activities of the multidisciplinary health care team (VANHAECHT *et al.*, 2010). According to the Brazilian Ministry of Health (BRASIL, 2014) care pathways are documents that establish criteria for the diagnosis of a health problem; the recommended treatment, with medicines and other appropriate products with the recommended dosages and the mechanisms of clinical control.

Clinical pathways are increasingly being used, in the United Kingdom, for example, they were introduced in the early 1990s and are used in combination with national guidance and local National Health Service policy to provide appropriate care in a local context (WEBER *et al.*, 2017; ZANDER, 2002), and currently, most health areas in the UK already have a care pathway approach (CPA, 2014). In the USA care pathways were used in more than 80% of hospitals in the late 1990s (VANHAECHT *et al.*, 2011). A study by Lopes and Ramires (LOPEZ; RAMIREZ,

2017) on the presence of clinical pathways in Central Europe, states that in some fields of medicine such as Oncology and Palliative Care, pathways have become the standard model of care. Medical errors can cost a patient their life and millions in damages to hospitals. This immense responsibility in health care processes warrants IT investment for process automation.

On the one hand, a care pathway can be seen as business processes (POELMANS *et al.*, 2010; SCHRIJVERS *et al.*, 2012; GOOCH; ROUDSARI, 2011), having a structure of a data-dependent transition system where there are some **states** as steps connected by a set of **transitions** (also called sequences). Some of these transitions have guard conditions whose logical operations define which one will be the next step in the execution. On the other hand, domain experts (doctors, nurses, etc.) are not aware of some formalism present in the syntax of business process languages such as gateways in BPMN (Business Process Model and Notation) (OMG, 2011); they just end up drawing boxes and arrows between them with a condition labeling these arrows.

Considering the importance of the correctness of these pathways and the fact that specialists will not follow a formal language to draw them, in this work, we develop a set of algorithms to check for four basic problems in pathways that follow the basic structure of boxes and arrows with labels. We follow the model-driven engineering paradigm (SCHMIDT, 2006), using a DSL (Domain Specific Language) (ANONSEN, 2005) with a Constraint Programming (CP) Solver (MILANO, 2018) to analyze all transitions and their guard conditions that could present satisfiability problems. The four possible logical problems we search for are:

- **Deadlock.** Finding deadlocks will prevent that pathway execution system gets blocked at any time while treating a patient;
- **Non-determinism.** Finding non-determinism will ensure that there is always one, and only one path to be followed given the current state, avoiding ambiguity during the treatment;
- **Inaccessible steps.** Finding inaccessible steps prevents states that will never run in a pathway;
- **Equivalent transitions.** Finding sequences with logically equivalent guard conditions helps to find redundancy in pathways, avoiding rework;

To find these problems, it is necessary to analyze all the sequences and their guard conditions that could present satisfiability problems. A constraint programming (CP) Solver (MILANO, 2018) is used to carry out the verification. It allows us to describe real combinatorial

problems in the form of constraint satisfaction problems and solving them with CP techniques. Constraint programming is basically a combination of a model developed to describe the problem through parameters, variables, constraint and an objective function; an input data describing a particular instance of the problem; a solver to satisfy the constraints in the model; and a search strategy to explore the search space (GOODWIN *et al.*, 2017).

We take a set of 113 real care pathways to test the algorithms modeled with specific characteristics by a group of stakeholders. The main contribution of this work is a tool that can help specialists in the modeling of safer pathways, mainly with regards to the transitions guard conditions.

1.1 Goals

The main goal of this work is to automate the process to check structural errors in the care pathways by developing a service that allows a straightforward verification in these pathways.

This automated verification tries to find four possible logical problems (deadlock, non-determinism, inaccessible steps and equivalent transitions) in a care pathway and returns, if any, cases of occurrence of such a problem, enabling its quick detection.

2 BACKGROUND AND MOTIVATION

To understand how the application works, we have to review the transition system concept, the structure of the care pathways and how it is executed, what possible logical problems may arise during the execution of a pathway and how a metamodel allied with a CP solver could help in verification of these pathways. All these issues will be described in the following subsections.

2.1 Transition System Concept

In this work, we will consider the most basic way of defining pathways: boxes and arrows between them; this is the way that most doctors, specialists use to define their workflows; see for example the book of knowledge of care pathways in the UK[1]. Considering this, we take care pathways as data-dependent transition systems. Them concepts are the basis for understanding how a care pathway behaves. There are many different definitions of transition systems in the literature, we use the one by Baier and Katoen (BAIER; KATOEN, 2008).

Transition systems (TS) are basically directed graph where nodes represent *states* and edges model transitions. The first one describes some information about a system at a certain moment of its behavior. The second one specifies how the system can evolve from one state to another. A TS can be seen as a tuple (S,Act,$\rightarrow$,I,AP,L) where:

- S is a set of states,
- Act is a set of actions,
- $\rightarrow \subseteq S$ x Act x S is a transition relation,
- $I \subseteq S$ is a set of initial states
- AP is a set of atomic propositions,
- L: $S \rightarrow 2^{AP}$ is a labeling function

The transition system starts in some initial state $s_0 \in I$ and evolves according to the transition relation $\rightarrow$. The action α, that triggers the change of state, is performed and the transition system advances from state s into state s'. The labeling function L relates a set $L(s) \in 2^{AP}$ of atomic propositions to any state s. atomic propositions are formalization of temporal characteristics, expressing simple known facts about the states of a system under consideration, as "$x = 1$", or "$x \geq 0$". $L(s)$ intuitively stands for exactly those atomic propositions

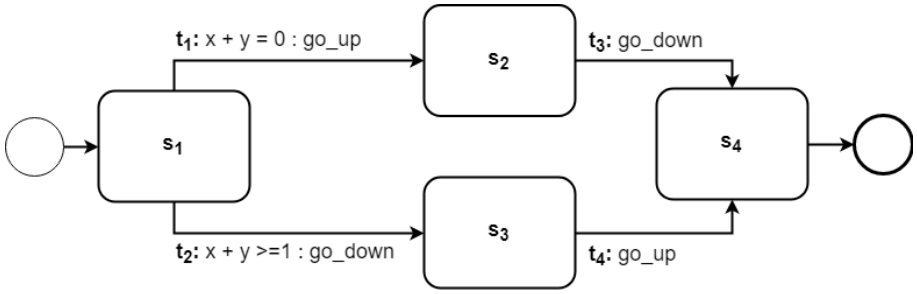
[1] https://pathways.nice.org.uk/

$a \in AP$ which are satisfied by state s.

However, in a data-dependent transition system the executable actions usually result from a conditional branching, this is the main difference between a transition system and a data-dependent transition system. The labels of conditional transitions are of the form $g : \alpha$ where g is a guard condition and α is an action that is possible once g holds. Guard condition is a boolean expression composed by a set *Var* of variables that could be Boolean, integer or character. Each variable has its own domain: the domain of a boolean variable, for example, is (0,1), an integer domain could be (0,1,2,3), $\mathbb{Z}$ or any set of integer numbers, and the domain of a character variable could be the letters from the alphabet. Note that the set of atomic propositions is composed of these variables and their possible values.

Figure 1 is a representation of a general data-dependent transition system where states are represented by rectangular shapes, the conditional transitions by the labeled arrows and non-conditional transition by empty arrows (notice that *go_up* and *go_down* are actions, therefore they do not label an arrow). The initial state is represented by the rectangular shapes connected with the thin border circle and the final states is the one connected with thick border circle.

Figure 1 – Flowchart of a general data-dependent transition system.



Source: made by the author.

In the example of Figure 1 we have four states with $S = \{s_1, s_2, s_3, s_4\}$ and $I = \{s_1\}$. There are also four transitions, with two conditional transitions t_1 and t_2 labeled with guard conditions $g_1 : x+y = 0$ and $g_2 : x+y >= 1$ respectively, and two non-conditional transitions t_3 and t_4. Thus we have the variables x and y. The set of actions is $Act = go\_up, go\_down$ which in the case of t_1 and t_2 the actions are only possible when g_1 or g_2 hold.

For this transition system we can consider the set of atomic propositions as being $AP = \{x = 0,\ x = 1,\ y = 0,\ y = 1\}$. Therefore we have as labeling function for each state:

- $L(s1) = \emptyset$
- $L(s2) = \{\{x{=}0, y{=}0\}\}$

- $L(s3)$ = {{x=0, y=1}; {x=1, y=0}; {x=1, y=1}}
- $L(s4)$ = {{$L(s2)$}; {$L(s3)$}}

Through the labeling function we can see which atomic propositions must be satisfied to reach a certain state. Since s_1 is the initial state it is not necessary for any proposition to be satisfied to reach it. Although transitions t_3 and t_4 have no guard conditions to be satisfied and the system can evolve to the next state, state s_4 requires that the previous states be satisfied so that it can be reached. Therefore subsequent states depend on the occurrence of previous states.

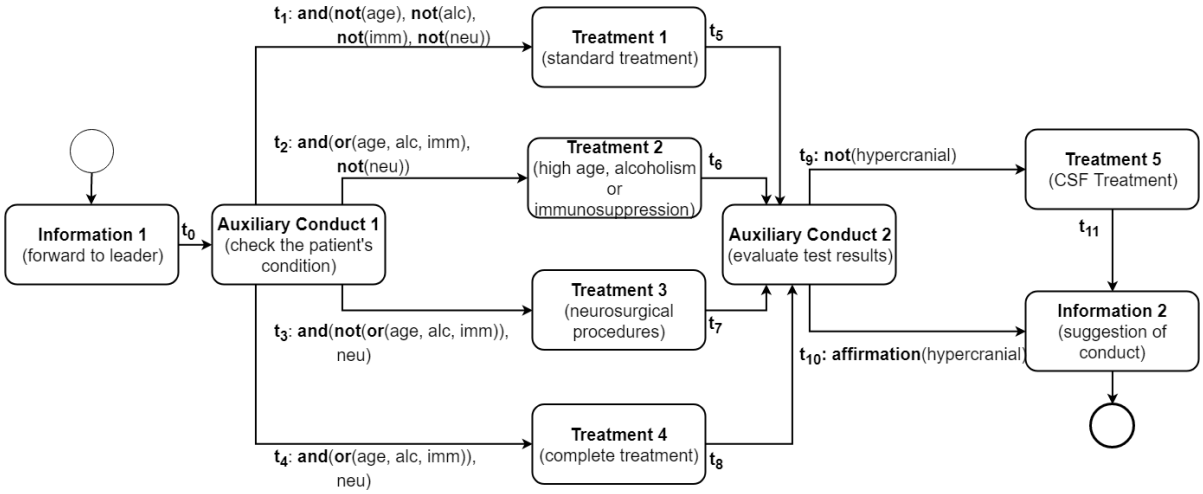
2.2 Care Pathway Structure

Care pathways are one of the main methods used to organize a care process and to improve quality and efficiency, being also a process on their own (VANHAECHT *et al.*, 2011; PANELLA *et al.*, 2003). They can be defined as an intervention for the mutual decision making and organization of predictable care for a well-defined group of patients during a well defined period, introducing and operationalizing the concept of patient-focused care (VANHAECHT *et al.*, 2007). Their development asks for a team of medical professionals that needs to review the available literature on the specific clinical topic and get evidence from both literature and operational research and patient involvement methodologies (VANHAECHT *et al.*, 2009; WENSING; ELWYN, 2003). The pathways studied in this work were modeled by a DSL developed by a multidisciplinary team of medical professionals and computer scientists with the process and logic-based knowledge to model the domain-specific language. Figure 2 shows a real example of the meningitis care pathway as a transition system. This pathway will be further discussed in detail.

We use a data-dependent transition systems to represent pathways, where states are elements, also called steps. In the case of these pathways, there are eight types of states: *Auxiliary Conduct*, *Prescription*, *Discharge*, *Referral*, *Treatment*, *Pause*, *Process* and *Information*. There is only one initial state, $|I| = 1$, but it may have more than one final state. The transition relations $\rightarrow$ that connect a state to another can be conditional or not. In these pathways every transitions has just one action: move on to next state; that is, $|Act| = 1$. Considering the action is the same for all transitions, it is omitted in the pathway. A state has a set of input transitions (T_{in}) and a set of output transitions (T_{out}). The initial state is the one that $T_{in} = \emptyset$ and $|T_{out}| > 0$.

The conditional transitions have an operation as the label (the guard condition g). An operation is a set of operands O related by an operator that could be a logical operator as *and*,

Figure 2 – Flowchart of meningitis care pathway.



Source: made by the author.

or, *xor* or *implies*, a relational operator as *equal*, *greater*, *less*, *greater or equal* and *less or equal*, an arithmetic operator as *addition*, *subtraction*, *multiplication* and *division*, or an unary operator such as *negation* and *affirmation*. An operand may be a variable or a constant from an operation and can be Numeric, YesOrNo (Boolean), Choice or other operation.

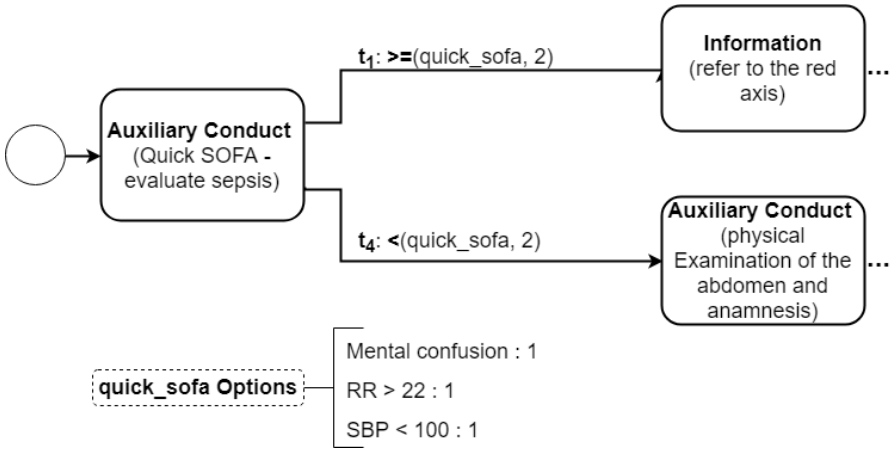
A Numeric operand is an integer constant or a variable whose domain is the set of integers $\mathbb{Z}$. A YesOrNo operand is a variable that domain is 0 or 1. The Choice operand is an integer variable composed by components called Option. Each Option has a weight that is added to the variable's value when chosen.

It is important to emphasize that, the three types of variables were defined by the stakeholders responsible for modeling the care pathways. And in the pathways analyzed, once a variable assumes a value during the pathway execution, it maintains that same value throughout the entire execution.

Figure 3 is a fragment of a real care pathway for treatment of abdominal pain with an example of Choice variable. There are three states, a *Auxiliary Conduct* when the doctor evaluates the risk of sepsis in the patient using quick sofa technique (an attempt to select patients with the highest potential for complication), a *Information* to refer the patient to a red axis and another *Auxiliary Conduct* to a physical examination of the abdomen and anamnesis. There are two transitions with a Choice variable named *quick_sofa*. These variable has three Option components *Mental confusion* verified by Glasgow Coma Scale, the respiratory rate greater than 22 ($RR > 22$) and systolic blood pressure less than 100 ($SBP < 100$), each one with weight 1 (the number after the colon indicates the Option weight). The doctor can select one or more Option components. If their weights sum is greater than or equal to two than the *Information* state is

running, otherwise the doctor perform the other *Auxiliary Conduct*.

Figure 3 – Flowchart of an abdominal pain care pathway fragment.



Source: made by the author.

2.3 Pathway Execution

For the modeled care pathways execution, there is a software system for generating screens from the initial pathway state and an interactive screen is generated for each state. Thus, for a treatment state, for example, it is generated a list with all medications, exams, and procedures that contained within the state and the physician can interact with these data by assigning values to variables, selecting medications required or making requests. For the physician to advance to a next state the system analyzes the variables, checking the guarding expressions of the current state output transitions and decides the next state to execute through the satisfied guard condition. When, due to a modeling error, there is more than one true guard condition or all are false, execution is paused because the system can not define the next step, presenting a problem of logical inconsistency and the pathway must be forwarded to the development team to be remodeled.

Intuitively, the behavior of the pathway represented in Figure 2 can be described as follows. The pathway starts with *Information 1*, which forwards the case to the team leader, which then in *Auxiliary Conduct 1* checks the patient's condition. From this state, the pathway evolves according to its transition relation to a *Treatment*. At this moment the doctor have to analyze 4 variables: *age*, *alc*, *imm* and *neu*. The first three variables represent aggravating conditions for the patient as, respectively, high age, alcoholism, and immunosuppression, the last variable "*neu*" represents the need for neurosurgical treatment. Therefore the pathway evolves

to *Treatment 1*, the standard treatment, if there are no aggravating conditions and no need for neurosurgical procedures, to *Treatment 2* if there are some aggravating conditions, to *Treatment 3* if neurosurgical procedures are necessary and there is no aggravating condition, and if there are some aggravating conditions and neurosurgical procedures are required then the pathway evolves to a complete treatment, the *Treatment 4*.

Each of the four treatments are connected to another *Auxiliary Conduct* by a non-conditional transition. In the *Auxiliary Conduct 2* the doctor evaluates the test results, then checks the presence of cranial hypertension in the patient, represented by the variable *hypercranial*. If the patient does not have cranial hypertension, the doctor submits it to a CSF (Cerebral Spinal Fluid) treatment, the *Treatment 5*, and then goes to the final state *Information 2* with suggestions of conduct as to maintain the empirical treatment. Otherwise, for patients with cranial hypertension, the pathway evolves directly into the final state with another suggestion of conduct. *Information 2* has more than one suggestion of conduct that might be used according to the patient's condition.

The state space is S = {*Auxiliary Conduct 1*, *Auxiliary Conduct 2*, *Information 1*, *Information 2*, *Treatment 1*, *Treatment 2*, *Treatment 3*, *Treatment 4*, *Treatment 5*}, with the initial state s_0 = *Information 1*. We have six operations as guard conditions from some transitions in all pathway {*and(not(age), not(alc), not(imm), not(neu))*; *and(or(age, alc, imm), not(neu))*; *and(not(or(age, alc, imm)), neu)*; *and(or(age, alc, imm)), neu)*; *not(hypercranial)*; *affirmation(hypercranial)*} with the set of operands *O*= {*age, alc, imm, neu, hypercranial*}. As the set of atomic proposition we have *AP* = {*age* = 0, *age* = 1, *alc* = 0, *alc* = 1, *imm* = 0, *imm* = 1, *neu* = 0, *neu* = 1, *hypercranial* = 0, *hypercranial* = 1} with the labeling function:

- $L(Information\ 1) = \emptyset$
- $L(AuxiliaryConduct1) = \{\{L(Information\ 1)\}\}$
- $L(Treatment\ 1)$= {{*age*=0, *alc*=0, *imm*=0, *neu*=0}}
- $L(Treatment\ 2)$ = {{*age*=1, *alc*=1, *imm*=1, *neu*=0}; {*age*=0, *alc*=0, *imm*=1, *neu*=0}; {*age*=0, *alc*=1, *imm*=0, *neu*=0}; {*age*=1, *alc*=0, *imm*=0, *neu*=0}; {*age*=1, *alc*=1, *imm*=0, *neu*=0}; {*age*=0, *alc*=1, *imm*=1, *neu*=0}; {*age*=1, *alc*=0, *imm*=1, *neu*=0}}
- $L(Treatment\ 3)$ = {{*age*=0, *alc*=0, *imm*=0, *neu*=1}}
- $L(Treatment\ 4)$ = {{*age*=1, *alc*=1, *imm*=1, *neu*=1}; {*age*=0, *alc*=0, *imm*=1, *neu*=1}; {*age*=0, *alc*=1, *imm*=0, *neu*=1}; {*age*=1, *alc*=0, *imm*=0, *neu*=1}; {*age*=1,

alc=1, imm=0, neu=1}; {age=0, alc=1, imm=1, neu=1}; {age=1, alc=0, imm=1, neu=1}}

- $L(AuxiliaryConduct2) = \{\{L(Treatment\ 1)\}; \{L(Treatment\ 2)\}; \{L(Treatment\ 3)\}; \{L(Treatment\ 4)\}\}$
- $L(Treatment\ 5) = \{\{L(AuxiliaryConduct2), hypercranial=0\}\}$
- $L(Information2) = \{\{L(AuxiliaryConduct2), hypercranial=1\}; \{L(Treatment\ 5)\}\}$

In this pathway, the propositions are all values that the variables age, alc, imm, neu and hypercranial can take. The *Information 1* is an initial state then it is not necessary for any proposition to be satisfied. The *Auxiliary Conduct 1*, does not need any propositions to be satisfied but still needs the previous state to be satisfied. The same goes for *Auxiliary Conduct 2* that requires at least one of the Treatments states (*Treatment 1, 2, 3 or 4*) be reached. In section 3.2 this labeling function is more explored.

The meningitis pathway version from the dataset of clinical pathways used for the test in this work is different from the version shown in Figure 2. In the dataset, it has 7 states, 9 transitions, and 4 operands. The state *Auxiliary Conduct 2* and *Treatment 5* were removed from the pathway as well as the transitions t_9, t_{10} and t_{11}, and the operand *hypercranial*, then all treatments states evolve to *Information 2* with more suggestions of conduct. We decided here to keep the 9 states pathway version which is more complete and suitable for demonstration.

By checking each transitions operations, we can find errors in the pathway structure, as well as predict possible problems in its execution, such as inaccessible steps and deadlock states. If we consider specific features from the analyzed pathways, we can verify even more problems. The pathways studied in this work are used by a single doctor treating a single patient per time. Therefore, in this scenario, incorporating parallelism is a complicating factor, as all operations are sequenced. We can imagine situations in which concurrency may be important (e.g., orchestration of surgery by multiple professionals), however, this was not the reality in the health organizations we had as partners. That is, it is not possible to have more than one state running at the same time. Thus we can consider two others problems: states in a situation of non-determinism, and states with output transitions that guard conditions are logically equivalent, being a cause of non-determinism.

2.4 Possible Problems in a Clinical Pathway

Assuming that S is the set of states in a pathway, the semantics of the model only allows a patient to be in one state at a time, and that the problems refer to a given state and not to the whole pathway; we can define the four possible issues addressed in our work as follows:

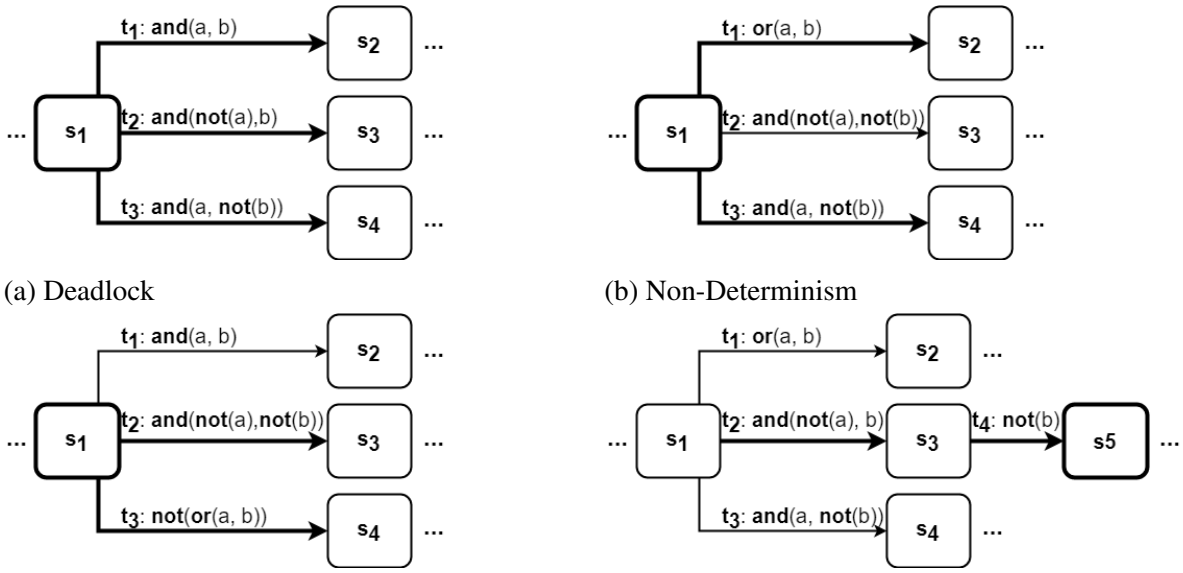
- **Deadlock:** being T_{out} a set of the output transitions of a state $s \in S$ and g_t the guard condition of $t \in T_{out}$. $\forall t \in T_{out}\ g_t = 0 \rightarrow s$ *is in deadlock*.
- **Non-Determinism:** being T_{out} a set of the output transitions of a state $s \in S$ and g_t the guard condition of $t \in T_{out}$. $\exists t_i \wedge \exists t_j \in T_{out} \mid t_i \neq t_j$, $g_{t_i} = g_{t_j} = 1 \rightarrow s$ *has a non-determinism problem*. Therefore it is not possible to resolve the next step.
- **Logically Equivalent Transitions:** being T_{out} a set of the output transitions of a state $s \in S$ and g_t the guard condition of $t \in T_{out}$. $\exists t_i \wedge \exists t_j \in T_{out} \mid t_i \neq t_j$, $g_{t_i} \equiv g_{t_j} \rightarrow t_i \equiv t_j$.
- **Inaccessible Step:** being T_{in} a set of the input transitions of a state $s \in S$ and g_t the guard condition of $t \in T_{in}$. $\nexists t \in T_{in} \mid g_t = 1 \rightarrow s$ *is inaccessible step*.

Figure 4 shows 4 generic examples of transition systems with the possible problems that can be found in clinical pathways. States and transactions that have a problem are represented in thicker black strokes. We can notice each TS has s_1, s_2, s_3 and s_4 as states and t_1, t_2 and t_3 as transitions, and in TS of Figure 4d besides the 4 states and 3 transitions it has state s_5 and transition t_4. Being all variables Boolean, then we can make some considerations:

Figure 4a shows an example of Deadlock. If we analyze the guard conditions of the 3 transitions, we will realize that they can take False values when $a = 0$ and $b = 0$, setting state s_1 in a deadlock situation. Another problem is addressed in transition system of Figure 4b. If the variables a and b take values 1 and 0 respectively, There will be a problem of non-determinism in state s_1, since transitions t_1 and t_3 are satisfied.

An example of equivalent transitions can be seen in Figure 4c. The transitions t_2 and t_3 have an equivalent guard conditions. No matter what the values take by a and b, the result will always be the same for both, making both True and False at the same time. This problem can cause a situation of non-determinism in the state s_1. Although the problem of logically equivalent transitions is a problem of non-determinism, it is interesting to analyze it separately because it is a more aggravating situation. Detecting logically equivalent transitions separately is important because it is the worst case of a non-determinism problem. Non-determinism may or may not occur, it will depend on the values that the variables in the guard will assume; however if there are

Figure 4 – Flowcharts of generic examples of potential problems



(a) Deadlock

(b) Non-Determinism

(c) Equivalent Transitions

(d) Inaccessible Step

Source: made by the author.

equivalent transitions, in the case of a satisfied transition, there will always be non-determinism problem, regardless of the values assumed by variables. Detecting this situation separately allows for earlier correction by modelers.

Analyzing the Figure 4d we notice a contradiction between transitions t_2 and t_4. The guarding condition of t_2 requires b takes true value so that it can be satisfied. However, the subsequent transition, t_4, requires b to be False, which would not be possible since b has already assumed True value. Thus state s_5 is an inaccessible state.

The 4 specific problems were motivated by a high-level manual analysis of existing pathways at partner hospitals. However, there may exist other possible problems, such as the existence of cycles. Cycles may sometimes cause pathways to get stuck and execute continuously without ever reaching a final state. Detecting cycles can be challenging and should be considered as the next step for our solution. Although we recognize it may occur, we have not found any cycles in the pathways used in this work during our manual inspection.

This section focuses on demonstrating the possible problems that can be found in a pathway, using generic examples of transition systems. However, in Section 3.2, we discuss how we can logically verify the existence or not of such problems in a real care pathway.

2.5 Model-driven engineering Approach for Care Pathways

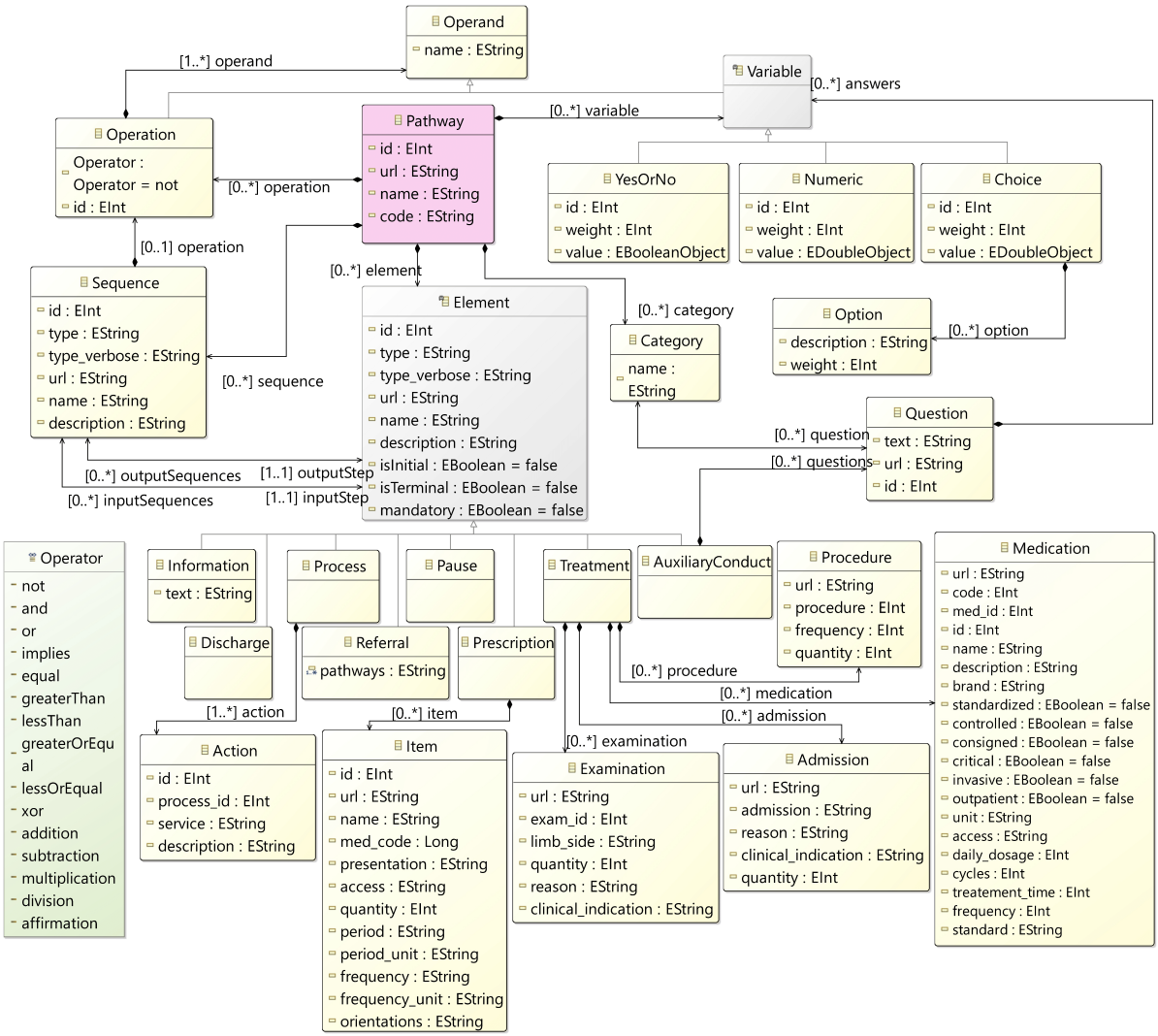
Model-driven engineering (MDE) is a software development methodology that creates domain models. These models help to understand complex systems and obtain results through a low level of abstraction improving the maintenance and evolution of the system (SELIC, 2003). It combines domain-specific modeling languages (DSML) with transformation engines and generators. The first one is described using meta-models, which define the relationships among concepts in a particular domain, such as online financial services, medicine, middleware platforms, and specify the key semantics and constraints associated with these domains. The second one analyzes certain aspects of models and then synthesize various types of artifacts, such as source code, XML deployment descriptions.

Although Model-driven engineering provides organized and structured methods for software development that allow for a number of perks such as code reuse, problem scope definition, ease of applicability, it is still considerably new in the Software Engineering field, therefore companies still walk towards it on a very slow pace. Most current languages and platforms, even with a high level of abstraction, are still computer-oriented. That is, they provided abstraction in the computing domain itself, rather than in the application domain, such as medicine, insurance and other kinds of industries. Large companies have already started to slowly employ MDE in their software development projects, so it can be expected to grow inside the corporate environments (MUSSBACHER *et al.*, 2014). Smaller businesses, however, have not yet presented a consistent use of MDE in their software, either by being unaware of its existence, alien to its methodology or afraid of employing new techniques into a growing business unsuccessfully (MOHAGHEGHI *et al.*, 2009; FRANCE; RUMPE, 2007).

The algorithms developed in this work makes use of a DSL (ANONSEN, 2005) created with the Eclipse Modeling Framework with the aim of generalizing the clinical pathway structure, modeling it with all its elements and flow conditions to ease the analysis process. This metamodel abstracts the features of a care pathway to specify its structure, being basically composed of elements that represent the medical conduct during the treatment process, i.e., states of the pathway, and also by elements used in the organization and in the flow control. In addition, the use of MDE provides greater portability and ease of reuse. The 113 pathways used to evaluate our solutions are designed with the aforementioned DSL and are the intellectual property of a health care provider company. See the abstract syntax of the DSL in Figure 5.

Figure 5 shows the abstract syntax of the metamodel. There are some differences

Figure 5 – Abstract Syntax of the DSL.



Source: made by the author.

between the nomenclature used in the metamodel and the one used in this work. In the metamodel, the states of a pathway are called elements, and transitions are named sequences. However, we can notice all the features of the clinical pathways used in this work: the states and their attributes; how transitions and operations are defined; the variables and possible operators; and how all these elements are related.

2.6 Constraint programming Solver

Constraint programming represents a real-world problem in terms of decision variables and constraints, and find an assignment to all the variables that satisfies the constraints, may be applied in many kinds of domains as operation research problems, business application and computer graphics (ROSSI *et al.*, 2006; NOUASRIA; ET-TOLBA, 2017). In CP approach,

it is possible to model a problem into a model with variables and their relations. Each variable has a range of values, then a CP solver tries each value to find solutions for the problem applying the problem's constraints (LOUËT; MENAUD, 2013).

We use the constraint programming Solver named Choco solver (PRUD'HOMME *et al.*, 2017). It is a satisfaction problem solver, using constraint programming techniques. There are many studies in the literature that use Choco for satisfiability problems, task optimization and as an alternative to Compressive Sensing algorithm (LOUËT; MENAUD, 2013; BAYINDIR *et al.*, 2014; NOUASRIA; ET-TOLBA, 2017). It is free and open-source software that is easy to use, extend and integrate into other software. Next, we describe some important definitions of Choco solver objects used in the project.

The key component from Choco is Choco Model. It should be the first instruction, prior to any other modeling instructions, as it is needed to declare variables and constraints. A variable has an unknown value whose domain must be defined in the Choco Model object. The goal of a resolution is to assign a value to each variable. Choco includes four types of variables, IntVar, BoolVar, RealVar and SetVar, but for this work, we used just the first two ones.

IntVar is an integer variable of Choco whose domain is a set of integers representing possible values. The domain of IntVar could be bounded, represented through an interval of the form $[a,b]$ where a and b are integers such that $a <= b$. And also the domain could be enumerated, represented through the set of possible values as $a,b,c,\ldots,z$ where $a < b < c < \ldots < z$. We can also define an "unbounded domain", defined by the maximum set of possible integers like $[Integer.MIN\_VALUE, Integer.MAX\_VALUE]$, however, it is recommended to define a domain that is close to expected values to avoid incorrect domain size or numeric overflow/underflow operations during propagation. When defining a domain we have to consider the memory consumption and the used constraints, cause domain types used may have a considerable impact on performance. Domains usually require a bitset, so enumerated domains are heavier in memory than bounded domain. Despite, an enumerated domain provides more information and takes advantage of the power of the filtering algorithm.

The BoolVars are Boolean variables. They are specific IntVar that take their value in $[0,1]$. BoolVar can be used to say whether or not a constraint should be satisfied as reification, besides that, their domain, and some filtering algorithms, are optimized.

There are also two other types of variables, *RealVar* and *SetVar*, although we do not use them in this work, it can be interesting to explain a little about them. *RealVar* is a variable

whose domain is an interval of doubles with its size constrained by a precision parameter for floating the numerical computation. A *SetVar* represents a set of integers and its domain id defined by a set interval with the upper bound as a set of integers object which contains integers that potentially figure in at least one solution and lower bound as a set of integers object with integers that figure in every solution, being a subset of the upper bound.

The constraints are restrictions over variables as a logic formula defining allowed combinations of values that must be satisfied to get a feasible solution. A constraint is equipped with a set of filtering algorithms, named propagators, that removes from variables domain values that cannot correspond to a valid combination of values. For a given problem there can be several constraints available, then a solution to a problem is variable-values assignment verifying all the constraints. Every constraint can be reified, that is, associated it with a BoolVar to represent whether or not the constraint is satisfied, thus the BoolVar takes value 1 when the constraint is satisfied and 0 when it is not.

Most of the time, constraint propagation is not sufficient to build a solution removing all values but one from variable domains. Thus the search space induced by variable domains needs to be explored using search strategies. A search strategy defines how to explore the search space by computing decisions that involve variables, values and operators. Decisions are computed and applied until all variables are instantiated and a solution has been found, or a failure has been detected. Choco Solver builds a binary search tree and used a default search based on Depth First Search, which splits variables according to their type and defines specific search strategies for each type.

3 APPROACH

The goal of this study is to develop a service to find possible logical problems in the structure of a care pathway. Therefore, this study aims at answering the following research questions:

- How to find deadlocks in clinical pathways?
- How to find non-determinisms in clinical pathways?
- How to find inaccessible steps in the pathways?
- How to find logically equivalent transitions in the pathway?

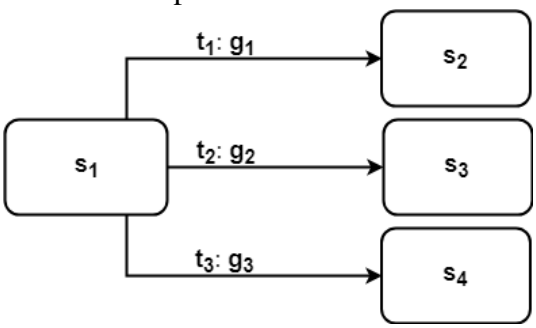
Based on these research questions, we developed a set of algorithms to verify the logical problems in clinical pathways with the use of model-driven engineering integrated with Choco solver. The service uses a DSL for structuring the care pathways and a constraint programming solver to analyze the operations in the pathways. Thus, there are four main functions, each one aiming at verifying one of the four problems. The subtopics below explain the behavior of these algorithms as well as the use of Choco to perform this verification. The algorithms are implemented and available in the <https://github.com/carepathways/Pathway-Verification.git>.

The 4 algorithms were developed to follow the set of care pathways states with their respective transitions to create a set of constraints. Thus, we build the satisfiability problems to be solved by Choco Solver. According to Choco's developers and our understanding after analysing choco's code, choco is commonly used to solve NP-Hard problems and has exponential time complexity. This makes all our algorithms to have exponential complexity at the worst case. However, the complexity of Choco Solver is directly related to the number of variables with their respective domains, and the number of constraints stated in the Choco Model (PRUD'HOMME *et al.*, 2017).

3.1 Logical Structure

Before understanding the algorithms we should understand how each state from a pathway is represented logically. Figure 6 and Table 1 show how the pathway states are logically structured for the set of algorithms. States, transitions and guard conditions are created as BoolVar. Each transition is true if and only if its guarding condition is satisfied. A state is true (or accessible) if and only if its input transition and the previous state were also satisfied. We can notice that the problems in a state are represented as a set of constraints.

Figure 6 – Flowchart of simple pathway representation.



Source: made by the author.

Table 1 – Logical representation of Figure 6

Pathway Objects	Logical Representation
State s	BoolVar $s \mid s = [0,1]$
Transition t	BoolVar $t \mid t = [0,1]$
Guard condition g	BoolVar $g \mid g = [0,1]$
t_i	$t_i \iff g_i$
s_2	$s_2 \iff t_1 \wedge s_1$
s_3	$s_3 \iff t_2 \wedge s_1$
s_4	$s_4 \iff t_3 \wedge s_1$
s_1 in Deadlock	$t_1 + t_2 + t_3 = 0$
s_1 with Non-determinism	$t_1 + t_2 + t_3 \geq 2$
s_1 with Equivalent transitions	$\forall t_1 t_2, t_1 + t_2 \neq 1$
	$\vee \forall t_1 t_3, t_1 + t_3 \neq 1$
	$\vee \forall t_2 t_3, t_2 + t_3 \neq 1$

Source: made by the author.

The algorithms to detect deadlock, non-determinism, and logically equivalent transitions analyze each pathway state, and verify irregularities present in a state, considering only the set of its output transitions, checking the guard conditions. That is, each state and its set of output transitions are analyzed individually. The inaccessible step detection algorithm performs a depth-first search in the pathway, constructing multiple paths with the initial state as its first element.

3.2 Running Example - Checking Problems at Meningitis Pathway

The meningitis pathway depicted in Figure 2 is an example of a well-designed pathway; to confirm this we need to make some observations: Analyzing the labeling functions of Meningitis Pathway in Section 2.3 we checked that every set of propositions are different, that is, there is no set of propositions in which more than one state can be reached at the same time. Therefore Meningitis Pathway is free of non-determinism problems.

We have to check for a deadlock. In the example of Figure 2, to know if a deadlock

can occur in a state such as the *Auxiliary Conduct 1*, we verify if we can reach at least one of the possible 4 next states (Treatment 1...4). This verification is done by iterating through the possible values of the 4 Boolean variables: *age, alc, imm and neu*; the possibilities are therefore equal to 2^4. For this particular example, we can check that any of the expressions guarding the treatments can be satisfied for at least one set of value attribution. In the second moment, to reach *Auxiliary Conduct 2*, it is only necessary the one of the four treatments(1 to 4) be executed, as *Auxiliary Conduct 2* is not guarded by any expression, implying that t_5, t_6, t_7 and t_8 are resolved to true. In a third moment, to reach the final state or *Treatment 5*, we have a new variable, *hypercranial*, then, considering the possibility of the previous state being reached, we have now 32 sets of possible values for the variables. We can also notice that transitions t_9 and t_{10} contemplate all these possibilities. Therefore, every set of propositions are satisfied by at least one of the guard conditions, that is, there are no deadlocks.

The inaccessible step problem takes a different approach. It is possible to detect an inaccessible step problem through a contradiction in the guard condition causing the labeling function to return an empty set, for example: making a small change in the guard condition of transition t_3 to *and(not(or(age, alc, imm, neu)), neu)* we get a new labeling function of *Treatment 3* which returns an empty set, $L(Treatment3) = \emptyset$, because it is not possible to have the variable *neu* be false and true at the same time and no set of propositions satisfy the guarding condition of t_3. We can conclude that Meningitis pathway has no inaccessible step problem. The only labeling function that returns the empty set is the initial state which is reachable by definition.

Now, we have to look at the problem of logically equivalent transitions, which generates a situation of non-determinism, but we already proved that in the Meningitis Pathway there is no state with non-determinism problems. To occur a equivalent transitions problem, we should have the following situation. Suppose $g_{t_1} =$ *and(not(age), not(alc), not(imm), neu)* and we have $g_{t_3} =$ *and(not(or(age, alc, imm)), neu)*, then $g_{t_1} \equiv g_{t_3}$ and $L(Treatment1) = L(Treatment3) = \{\{age{=}0, alc{=}0, imm{=}0, neu{=}1\}\}$. Whenever the guarding condition from one of this transitions is satisfied, the other one is satisfied as well. Therefore we have $t_1 \equiv t_3$, causing the state *Auxiliary Conduct 1* to have a non-determinism problem.

3.3 Algorithms

We have already seen how the pathway is logically structured and how we can check if a real pathway is well modeled. Now we can understand how the algorithms really work and

how to transform a transition into a BoolVar by building rectified constraints.

3.3.1 Transform Transitions to BoolVars

The 4 algorithms use a function to transform a list of transitions to a list of BoolVar named *sequenceListToBoolVarList*. It gets as input a set of transitions and a Choco model m, runs over all transition in the set, transforms them to BoolVar calling another function *sequenceToBoolVar* (Algorithm 1), inserts them in a set of BoolVar and returns it. This other algorithm receives as arguments the Choco model m where the constraints should be created, a transition t to be transformed in a BoolVar, a BoolVar set V_b and IntVar set V_i to store the operands as a BoolVar and IntVar variables respectively.

Algorithm 1: sequenceToBoolVar (m, t, V_b, V_i)

Input : a Choco model m, a transition t, a set of BoolVar V_b and a set of IntVar V_i.

Output : a sequence representation as a BoolVar b.

```
1 start
2     operation ← GETOPERATION(t);
3     OPERANDSINTOLISTS(V_b, V_i, m, operation);
4     b ← CREATEBOOLVARSEQUENCE(operation, V_b, V_i);
5     return b;
```

In lines 2 and 3 from Algorithm 1 we use two other functions, *operandsIntoLists* and *createBoolVarSequence*. The first one transforms the operands from a transition operation to BoolVars or IntVars variables and adds them into the sets V_b or V_i respectively. This function checks all the operands inside operation and verifies if they are Numeric, Boolean, Choice or another operation. We create an IntVar for each Numeric operand. The variable's domain is enumerated if the operand has no default value. Otherwise, it is a constant with the same value as the operand. We use a slightly different approach for Boolean operands. In arithmetic operation a Boolean operand has a weight that is used when the operand is true, therefore it is described as an IntVar whose domain is enumerated with zero and the weight. For other types of operations, we use a normal boolean variable. For Choice operands, we create an enumerated IntVar whose domain includes zero, the set of possible weights attributed to Option components, and the possible combinations of their sums. If the operand is another operation, the function is called recursively.

The *createBoolVarSequence* function is an algorithm that analyze the existing operators in the operation to transform an operation of a sequence into BoolVar reified with constraints. We create this constraints by applying BoolVars and IntVars from V_b and V_i sets. For logical and relational operators, if the operation has another operation as its operand, this function is called recursively. For arithmetic operators another function is called to calculate the expression.

Choco model has a method called *arithm* to create a constraint. Table 2 shows the corresponding constraints according to operation. For representing the logical operator *and* between two BoolVars we have to create a new BoolVar b that is true only if the sum of those two BoolVars is 2, since a BoolVar can only be 0 or 1. We use the same rationale for other logical operators. The relational operator works in a similar way. An equality will only be a BoolVar reified as an equality of the two others BoolVars. The unary operation may be an affirmation of a BoolVar, setting the new BoolVar B to 1 if the older one is 1 too, or a negation, setting B to 1 if the older BoolVar is 0. These constraints can be posted on the Solver or reified to a new BoolVar that can be a representation of a transition constrained by its operation.

Table 2 – Constraints for the Operations

Operators	Constraints
And	$model.arithm(B_1, +, B_2, =, 2)$
Or	$model.arithm(B_1, +, B_2, \neq, 0)$
Xor	$model.arithm(B_1, +, B_2, =, 1)$
Implies	$model.arithm(B_1, -, B_2, \neq, 1)$
Equal	$model.arithm(I_1, =, I_2)$
Greater or Equal	$model.arithm(I_1, \geq, I_2)$
Less or Equal	$model.arithm(I_1, \leq, I_2)$
Greater Than	$model.arithm(I_1, >, I_2)$
Less Than	$model.arithm(I_1, <, I_2)$
Not	$model.arithm(B_1, =, 0)$
Affirmation	$model.arithm(B_1, =, 1)$

Source: made by the author.

Some operations have arithmetic operations inside, and they require to calculate the possible results of this operations and not only creating a constraint. We use IntVars methods to calculate these operations that transform it in another IntVars with all possible results as their domain, i.e. for the multiplication of two IntVars is generated a new IntVar whose domain is the set of all possible results of this multiplication.

3.3.2 Finding deadlock

Algorithm 2 is suited for finding states is in deadlock. First of all, in line 3, the algorithm iterates over the size of the map M_s with the pathway states as key and their respective output transitions as values. In lines 4 to 6 the Choco model is instantiated; we get a set of transitions T_{out} from the set of map values and use function *sequenceListToBoolVarList* to transform T_{out} in a set of BoolVar B.

We then iterate over all BoolVar b in B, setting b to false and post it as the constraint on Choco model. This is the constraint that indicates we are searching for a deadlock state. In line 9 we get the Solver, an object obtained from Choco model in charge of alternating constraint-propagation with search and learning in order to compute solutions. In line 10 we get the origin state, s, of the transitions from the set of map keys.

Finally, in line 11, we use the method *findSolution* from *solver* to attempt to find a solution of the declared satisfaction problem, i.e. a deadlock case in s. We then, at the same line, add s to a map M_r as a key and the solution returned by *findSolution* as the value. At the end of the algorithm we return M_r with the states and their respective deadlock cases. In this case, the solution is the set of variables with their respective values that results in deadlock. An empty solution indicates the impossibility of deadlock.

Algorithm 2: findDeadlockSolutions (M_s)

Input : A map of states with the sets of their respective output transitions M_s.

Output : A map M_r of states with the deadlock case for each state.

```
1  start
2      M_r ← ∅;
3      for i ← 0 to SIZE(M_s) do
4          m ← MODEL();
5          T_out ← VALUES(M_s)[i];
6          B ← SEQUENCELISTTOBOOLVARLIST(m, T_out);
7          forall b ∈ B do
8              Post ARITHM(b = 0);
9          solver ← GETSOLVER(m);
10         s ← KEYS(M_s)[i];
11         M_r ← M_r ∪ {s, FINDSOLUTION(solver)};
12     return M_r;
```

3.3.3 Finding non-determinism

Algorithm 3 is used to find states with non-determinism problem and return a situation (solution) with the problem. As in the deadlock algorithm, it starts by iterating over the size of the map M_s, instantiates the Choco model, gets a set of transitions T_{out} from map values and gets a set of BoolVar B from T_{out}. In lines 7 to 12 we take two BoolVars from B, set both to true as constraint on Choco model, get the solver from the model and the origin state from the map keys and add the state and a case with the non-determinism problem in a map M_r. In the next lines we reset the solver, remove the last constraint in Choco model and verify if M_r has at least one solution to break the interaction. In the end we return M_r.

Algorithm 3: findNonDeterminsimSolutions (M_s)

Input : A map of states with the sets of their respective output transitions M_s.

Output : A map M_r of elements with the non determinism case for each states.

```
1  start
2      M_r ← ∅;
3      for i ← 0 to SIZE(M_s) do
4          m ← MODEL();
5          T_out ← VALUES(M_s)[i];
6          B ← SEQUENCELISTTOBOOLVARLIST(m, T_out);
7          forall b_0 ∈ B do
8              forall b_1 ∈ B with INDEX(b_1) > INDEX(b_0) do
9                  Post ARITHM(b_0 + b_1 = 2);
10                 solver ← GETSOLVER(m);
11                 s ← KEYS(M_s)[i];
12                 M_r ← M_r ∪ {s, FINDSOLUTION(solver)};
13                 Reset the solver from Choco model and unpost the last constraint;
14                 if SIZE(M_r) > 0 then
15                     break;;
16     return M_r;
```

3.3.4 Finding Inaccessible Steps

We use a different approach to find inaccessible steps (Algorithm 4). We get the set S of all states in the pathway and then we try to find all accessible states to prune the set S,

getting the inaccessible ones. First, we initialize some sets: set S_a to store accessible steps, V for the steps visited, the *Stack* in which we create a path to perform the search, and set T of transitions that connect the states from *Stack*. All these sets start with the initial step, but T. We then iterate over *Stack*.

In lines 5 to 7 we declare the Choco model, take the state s_0 from the top of *Stack* and with method GETNEXTSEQUENCE(s_0, V) we get the next output transition to be verified. This method checks for an unvisited state, add it to V and returns the unverified transition that connect s_0 to this state; otherwise return null. Getting null as t_{out}, we remove s_0 from the *Stack* and the last transition from T. Otherwise, we add t_{out} to T, transform T into a set of BoolVars B, and post in Choco model the constraint to check if the next step is accessible by the path built in T (all transitions labels of T have to be satisfiable). Then we add the next step s_1 to S_a if there is at least a solution with those constraints and add it to the stack if it has at least one output sequence; otherwise remove the last transition from T. The same is done if there is no solution to the set of constraints. At the end we use the *getInacessibleElements* function to remove all accessible steps from S and return the result.

3.3.5 Finding Logically Equivalent Sequences

Algorithm 5 checks for logical equivalence in operations of two or more transitions with the same output step. Initially we get a set of transition T_{out} from values of the map M_s and transform it into a set of BoolVar B. We analyzed the possibility of two different transitions with the same origin state to present different values, thus, at lines 7 to 10, we iterate over all the BoolVars in B, creating as constraints the sum of two different BoolVars in B is 1. If we find no solutions, the two BoolVars are logically equivalent and the transitions represented by these BoolVars are added in a set of logically equivalent transitions T_{LET}. In lines 16 and 17, we add T_{LET} to M_r with the respective output state and return it.

Algorithm 4: findInaccessibleSteps (S)

Input : A set S of the pathway states.

Output : A set of inaccessible states S_i.

```
1  start
2      S_a, V, Stack ← GETINITIALELEMENT(S);
3      T ← ∅;
4      while Stack is not empty do
5          m ← MODEL();
6          s_0 ← LASTELEMENT(Stack);
7          t_out ← GETNEXTSEQUENCE(s_0, V);
8          if t_out = null then
9              Remove s_0 from stack and the last transition from T;
10         else
11             T ← T ∪ t_out;
12             B ← SEQUENCELISTTOBOOLVARLIST(m, T);
13             forall b ∈ B do
14                 Post ARITHM(b = 1);
15             solver = GETSOLVER(m);
16             if FINDSOLUTION(solver))} ≠ null then
17                 s_1 ← IMPUTSTEP(t_out);
18                 S_a ← S_a ∪ s_1;
19                 Add s_1 in stack;
20                 if OUTPUTSEQUENCES(s_1) ≠ null then
21                     Add s_1 in stack;
22                 else
23                     Remove the last transition from T;
24             else
25                 Remove the last transition from T;
26     S_i ← GETINACCESSIBLEELEMENTS(S, S_a);
27     return S_i;
```

Algorithm 5: findLogicallyEquivalentSequences (M_s)

Input : A map of states with the sets of their respective output transitions M_s.

Output : A map M_r of elements and their logically equivalent output transitions.

```
1  start
2      M_r ← ∅;
3      for i ← 0 to SIZE(M_s) do
4          m ← MODEL();
5          T_out ← VALUES(M_s)[i];
6          B ← SEQUENCELISTTOBOOLVARLIST(m, T_out);
7          forall b_1 ∈ B do
8              forall b_2 ∈ B with INDEX(b_2) > INDEX(b_1);
9              do
10                 Post ARITHM(b_1 + b_2 = 1);
11                 solver ← GETSOLVER(m);
12                 if FINDSOLUTION(solver) is empty then
13                     T_LET ← T_LET ∪ SEQUENCE(b_1) ∪ SEQUENCE(b_2);
14                 Reset the solver from Choco model and unpost the last constraint posted;
15         s ← KEYS(M_s)[i];
16         M_r ← M_r ∪ {s, T_LET};
17     return M_r;
```

4 EVALUATION

In the previous chapter, we answer some research questions about how we detect the problems in care pathways. Now we have other questions about the applicability of the algorithm presented in Chapter 3; after all, can we detect the problems addressed in this work in real clinical pathways? Thus, in this chapter, we answer four more research questions.

- Can we find deadlocks in real clinical pathways?
- Can we find non-determinisms in real clinical pathways?
- Can we find inaccessible steps in real clinical pathways?
- Can we find equivalent transitions in real clinical pathways?

In the sections below we explain the pathways dataset in which the algorithms were applied, the results, as well as the efficiency of the algorithms in detecting the problems.

4.1 Pathways Dataset

The algorithms were tested with a set of 113 real care pathways used in medical environments (both hospital and clinical). Since October 2017, these pathways have been used in about 1.68 million patient care services in 39 medical units in Brazil. And the number of pathway executions can be even larger, considering that a service can trigger more than one protocol over its duration (by the occurrence of Referrals). These pathways were modeled by a group of stakeholders consisting mainly of computer scientists and medical professionals, and they are translated into a more suitable format to perform the checks. Table 3 shows the 14 pathways from the dataset used in this study with the number of states, transitions, and possible paths. They are ordered by the number of states, and we can see the 7 largest pathways concerning the number of states and the 7 minor ones. See the full table at Appendix A.

Initially, the dataset contained 120 pathways, however, 7 of them presented inconsistency with the model. Some contained isolated transitions (transitions without output and input states) something that is not allowed by the model. Others had incoherent logical operations, such as a unary operator with two operands, making it impossible to verify satisfiability problems.

4.2 Results and Findings

We run the algorithms on a personal computer with a quad-core processor Intel Core i7-2670QM and 8GB RAM. In the tests performed, we found several cases of deadlocks (179)

Table 3 – Care pathways dataset.

Pathway	States	Transitions	Paths
(H) Pediatric URTI	49	63	31
(H) Woman Abdominal Pain	43	45	22
(H) Pediatric Abdominal Pain	39	45	27
(C) Diabetes Treatment	38	53	15
(C) Diabetes Mellitus	38	53	15
(H) Chest Pain	38	44	30
(C) Allergic Rhinitis	36	35	27
⋮	⋮	⋮	⋮
(H) Check Sepsis	5	5	4
(C) ACEI BBC Betablocker	4	3	3
(H) Pediatric Septic Arthritis	4	3	2
(H) Check Arbovirus	4	3	3
(H) Bandage	3	2	2
(H) Puerperal Endometritis	3	2	2
(C) Verify Episode (UTI)	1	0	1

Source: made by the author.

and non-determinism (100), some cases of inaccessible steps (16) and no case of equivalent transitions. Table 4 shows 14 pathways from the total of 113 analyzed in this study, the 7 pathways that require the most time for performing the algorithms and the 7 that performed faster; they are ordered by time spent to search for the four problems. Table 4 also shows the number of deadlocks, non-determinism, inaccessible steps, and equivalent transitions, the number of binary search trees built by the solver and the number of nodes in the trees. See the full table at Appendix B.

Table 4 – The pathways and the found problems.

Pathway	Dl	ND	IS	ET	BT	N	Rt(ms)
(H) Stroke	2	0	0	0	13	25198162	900631,2377
(C) Hypothyroidism	1	2	0	0	44	8141877	133349,094
(H) Pneumonia Influenza	0	0	0	0	25	135356	2935,423889
(H) Pediatric Abdominal Pain	1	0	0	0	140	368	1681,503843
(C) Headache	3	3	0	0	52	8531	114,279475
(C) ACEI BBC Betablocker	1	0	0	0	10	415	62,81959
(C) Backache	1	1	0	0	34	1420	54,823821
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
(H) Check Arbovirus	1	0	0	0	7	12	0,50388
(H) Exposed Fracture	1	1	0	0	8	10	0,486292
(H) Pediatric Septic Arthritis	0	0	0	0	4	5	0,461148
(H) Pediatric Laryngitis	0	0	0	0	7	9	0,442721
(C) FP UTI	0	0	0	0	6	7	0,408945
(H) Bandage	0	0	0	0	3	4	0,281306
(C) Verify Episode (UTI)	0	0	0	0	0	0	0,010588

Source: made by the author.

Note: Dl = Deadlock; ND = Non-Determinism; IS = Inaccessible Step; ET = Equivalent Transitions; BT = Binary Tree Number; N = Nodes Number; Rt = Runtime in millisecond;

The last column of Table 4 shows the average runtime. These time values were achieved by running the four main algorithms for each pathway 12 times. We excluded the highest and the lowest execution time values and calculate the average of the 10 remaining values, and then we get the average execution time of a pathway for each algorithm. Adding the 4 execution times, we have a total average time for each pathway. We use time values to define the complexity of the pathways. For the sake of comparison, when the search takes less than 1 millisecond we named it as a low complexity pathway; more than 1 millisecond but less than 1 second we named it as a medium complexity pathway; as high complexity if it takes more than 1 second to check for the problems; and as of very high complexity if more than 1 minute is needed. Table 5 shows the pathways grouped by the level of complexity. We can notice that the runtime is less than one second in most cases (96,4%), except for 4 pathways (Stroke, Hypothyroidism, Pneumonia Influenza and Pediatric Abdominal Pain) that have more complex operations and require more time to run.

Table 5 – Pathway complexity level.

Complexity Level	Pathways Nº	Percentage (%)
Low	19	16,8
Medium	90	79,6
High	2	1,8
Very High	2	1,8

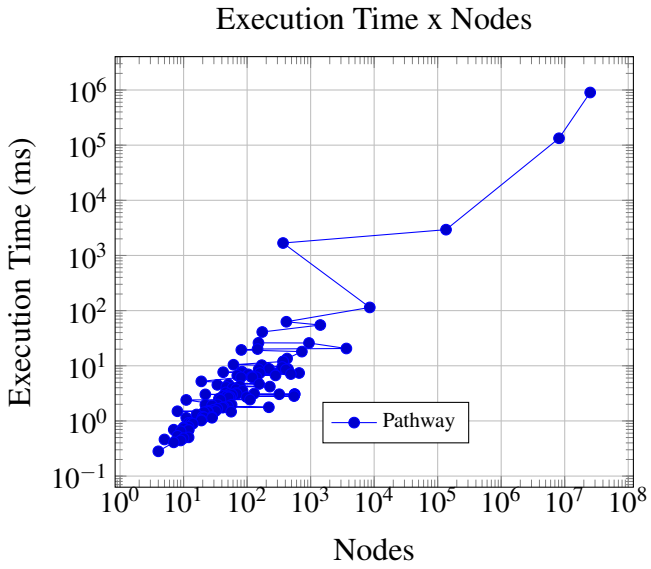
Source: made by the author.

We know in most cases Choco Solver needs to create a binary search tree to find a solution to a satisfiability problem. Graph 7 relates the execution time of each pathway with numbers of nodes present in the binary search trees.

The execution time of the algorithms tends to increase according to the number of nodes analyzed by the Solver. Thus, we can infer that the size of the binary tree interferes directly in the time required for execution.

The runtime, number of nodes and number of binary trees shown in Table 4 represent a total value for all 4 algorithms. However, some of the algorithms may take considerably longer to execute a particular pathway. Thus, for a more complete analysis, it is interesting to analyze the results of each algorithm individually.

Figure 7 – Graph of relation of execution time by number of nodes.



Source: Made by the author.

4.2.1 Deadlock Evaluation

Although the deadlock algorithm is the shortest of the 4 algorithms, this does not imply in faster performance. Table 6 shows the performance of the deadlock algorithm to each pathway ordered by the execution time and also with the number of binary trees created e number of nodes (see the full table in Appendix C). Whereas the Stroke pathway is the one that requires more time to execute all the algorithms, it is interesting to notice that Hypothyroidism and Pneumonia Influenza pathways take much longer to perform in this case. This shows that depending on the type of constraint created, the search for a solution can lead to a binary search tree with more nodes and take more time to execute, not being a standard for the pathway itself. As said in the previous chapter, Chapter 3, the number of variables and constraints directly affects the execution time of the algorithms for each pathway. In the case of these clinical pathways, the type of the variable will also interfere. YesOrNo (Boolean) variables whose domain ranges only from 0 to 1 are far more efficient than Numeric or Choice variables, whose domain can be much larger, generating a range with numerous result possibilities that Choco Solver should test.

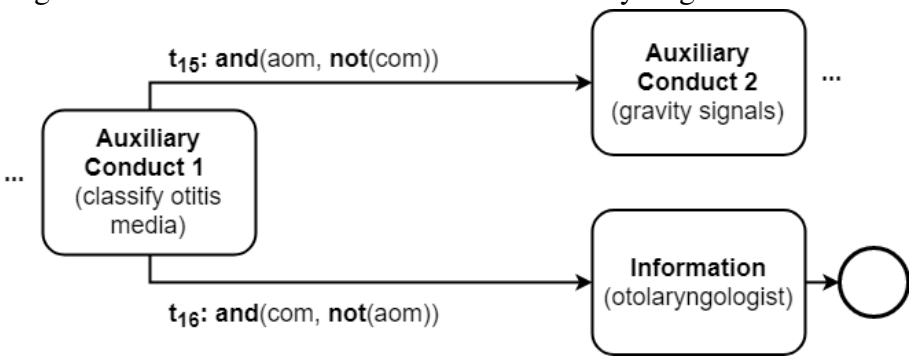
Figure 8 is an Earache Pathway fragment which has a deadlocked state detected by Algorithm 2. In this fragment, we can see 3 states and 2 conditioned transitions both with the Boolean variables *aom* (acute otitis media) and *com* (chronic otitis media). The algorithm reports the possibility of deadlock occurring in state *Auxiliary Conduct* to classify otitis media, presenting a deadlock case: $aom = 1$ and $com = 1$.

Table 6 – Deadlock algorithm evaluation.

Pathway	Binary Trees	Nodes	Runtime (ms)
(C) Hypothyroidism	4	4186157	72003,59365
(H) Pneumonia Influenza	1	67558	1583,499031
(H) Pediatric Abdominal Pain	1	2	68,817559
(C) Headache	7	4092	61,656245
(C) ACEI BBC Betablocker	1	128	22,153111
(C) Backache	2	546	18,420906
(C) Joint Pain	3	13	12,604225
⋮	⋮	⋮	⋮
(H) Exposed Fracture	1	1	0,19099
(C) FP UTI	0	0	0,187025
(H) Pediatric Laryngitis	0	0	0,134916
(H) Check Arbovirus	1	2	0,129411
(H) Bandage	0	0	0,115835
(H) Pediatric Septic Arthritis	0	0	0,114622
(C) Verify Episode (UTI)	0	0	0,001539

Source: made by the author.

Figure 8 – Flowchart of a Earache Care Pathway fragment.



Source: made by the author.
Note: aom = acute otitis media; com = chronic otitis media

By checking the transitions t_{15} and t_{16}, we can easily conclude the case presented by the algorithm would result in a false value for both guard conditions, making it impossible for the pathway execution to evolve to a next state. We can also realize that for $aom = 0$ and $com = 0$, the state is also in deadlock. Although there is more than one case where state *Auxiliary Conduct 1* is deadlocked, the algorithm returns only one case. See Appendix G to see all deadlock cases found in the dataset.

The choice to return a single case of the problem was made for 2 reasons. Firstly, it improves the performance of the algorithms, because it runs faster and avoids memory overflow in an attempt to find all problems. The second reason is that for each state of a pathway there may be several cases that result in the same problem. Returning them would result in a longer and exhausting reading by the application user while returning a single case is enough to know that a particular state of a pathway has a potential problem.

4.2.2 Non-Determinism Evaluation

The problem of non-determinism is the second most frequent problem in the pathways tested. We can see the algorithm's performance to detect this problem in Table 7 (full table in Appendix D). In this case, we notice a great difference to execute the Stroke pathway, both at runtime and node numbers. Although the execution of the algorithm of non-determinism under the Pneumonia Influenza pathway takes a similar time to the execution of the deadlock algorithm, a high time in relation to the great majority, the Stroke pathway, which was not even among the 7 pathways with longer runtime on Table 6, required much more time.

Table 7 – Non-determinism algorithm evaluation.

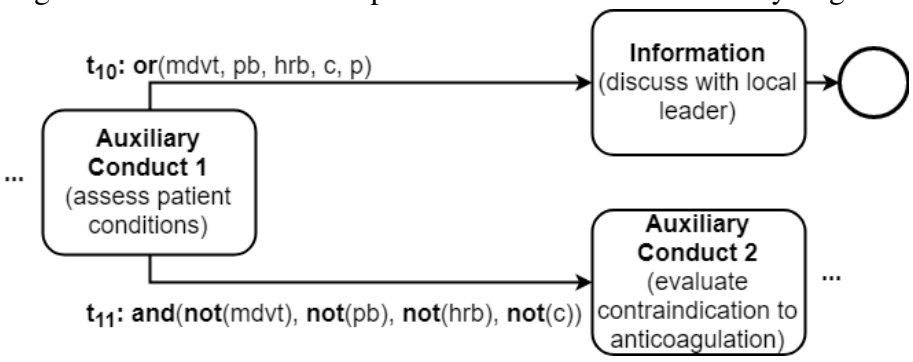
Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Stroke	1	25197558	900609,5035
(C) Hypothyroidism	6	3955244	61333,98003
(H) Pneumonia Influenza	1	67558	1344,124234
(H) Pediatric Abdominal Pain	0	0	55,26104
(C) Headache	10	4086	45,728482
(C) ACEI BBC Betablocker	3	72	14,170265
(C) Backache	5	458	11,348696
⋮	⋮	⋮	⋮
(C) ACEI Line Tripletherapy	0	0	0,11103
(C) African American Pharmacological	0	0	0,107671
(H) Pediatric Laryngitis	0	0	0,087331
(H) Exposed Fracture	1	1	0,082572
(C) FP UTI	0	0	0,06144
(H) Bandage	0	0	0,049404
(C) Verify Episode (UTI)	0	0	0,000886

Source: made by the author.

We can see a real example of a non-determinism situation found by Algorithm 3 in Deep Vein Thrombosis Pathway (Figure 9). The fragment of Figure 9 shows us 3 states, 2 conditioned transitions and 5 Boolean variables from Deep Vein Thrombosis Pathway. According to the algorithm, there is a problem of non-determinism in state *Auxiliary Conduct* to assess patient conditions when variables *mdvt*, *pb*, *hrb*, *c* and *p* take the values 0, 0, 0, 0 and 1 respectively.

We can attest to the existence of non-determinism in Deep Vein Thrombosis Pathway because in the case shown by the algorithm, the 2 guard conditions of transitions t_{10} and t_{11} are satisfied, leading state *Auxiliary Conduct 1* to a non-deterministic situation. We notice that the problem is the variable *p*, indicative for pregnancy, whose value is disregarded in the guard condition of t_{11}. See all non-determinism cases found in Appendix H.

Figure 9 – Flowchart of Deep Vein Thrombosis Care Pathway fragment.



Source: made by the author.
Note: mdvp = massive deep vein thrombosis; pb = pulmonary embolism; hrb = high risk of bleeding; c = comorbidities; p = pregnancy

4.2.3 Inaccessible Steps Evaluation

The algorithm to find inaccessible steps works different from the others and perform a depth-first search. In Table 8 we can notice that the execution time for each pathway are quite close to each other, there is a variation of less than 21 ms for the second pathway that took more time (Pneumonia Influenza) to the one that took less time (Verify Episode) (see full table in Appendix E). Pediatric Abdominal Pain pathway stands out as the pathway that takes more time, considerably longer time to the others.

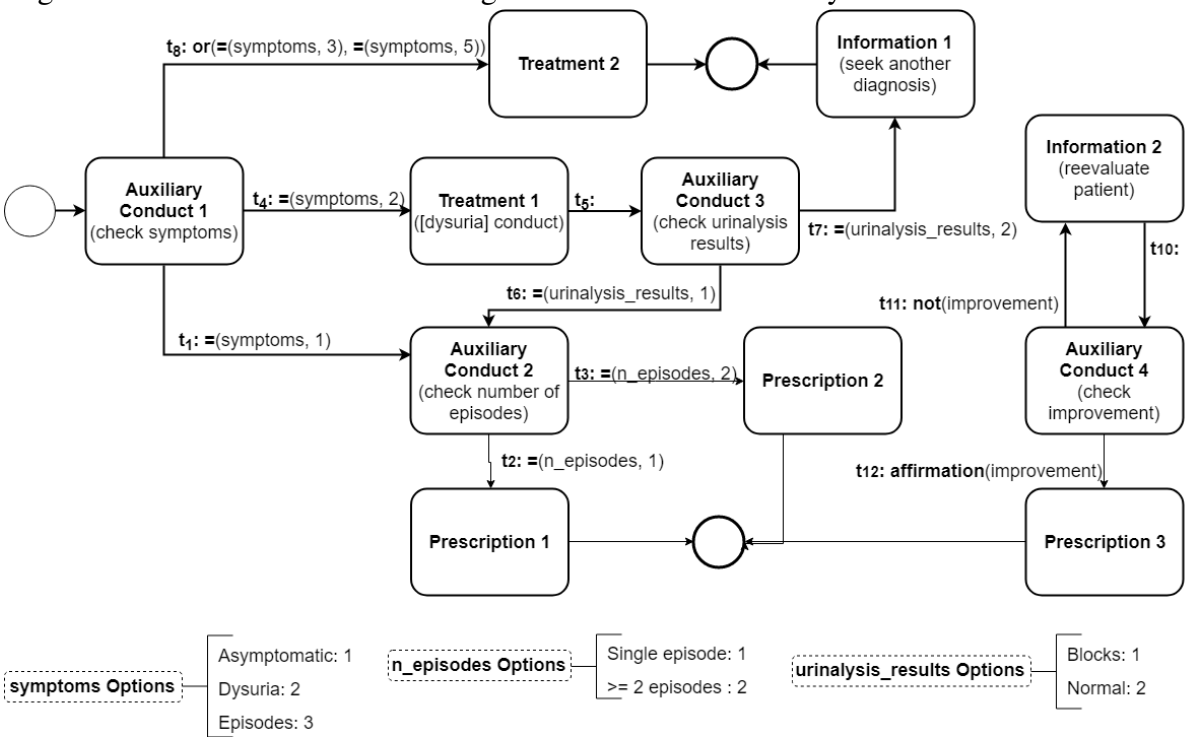
Table 8 – Inaccessible steps algorithm evaluation.

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Pediatric Abdominal Pain	38	38	1503,560667
(C) Backache	18	214	20,61618
(H) Pediatric URTI	48	55	15,032336
(H) Hypertensive Syndrome	23	38	14,547022
(H) Deep Vein Thrombosis	15	34	14,495192
(C) Joint Pain	27	66	14,182908
(C) Allergic Rhinitis	34	289	13,938174
⋮	⋮	⋮	⋮
(C) African American Pharmacological	4	4	0,129924
(H) Pediatric Laryngitis	5	5	0,129411
(H) Exposed Fracture	4	4	0,125119
(C) FP UTI	5	5	0,099974
(H) Pediatric Septic Arthritis	3	3	0,071237
(H) Bandage	2	2	0,064658
(C) Verify Episode (UTI)	0	0	0,007371

Source: made by the author.

Although we found no case of contradiction in the guard conditions of the tested pathways, we detected some inaccessible steps, as can be seen in Table 4. Figure 10 is an example of a real pathway with 3 inaccessible states. See all inaccessible steps found in Appendix I.

Figure 10 – Flowchart of UTI in Pregnant Women Care Pathway.



Source: made by the author.

UTI in Pregnant Women Pathway (Figure 10) has a total of 11 states, 11 transitions (9 conditioned and 2 unconditioned), 3 Choice variables and 1 Boolean variable. Running Algorithm 4 on this pathway results in 3 inaccessible steps: the state *Information* to reevaluate patient, the *Auxiliary Conduct* to check improvement and *Prescription 3*. Knowing that *Auxiliary Conduct 1* is the initial state, we notice that no path connects this initial state to any of those 3 states. That is, these 3 states form an isolated set from the pathway that will never be executed. It is interesting to notice the absence of the transition t_9. This transition could be a connection between the set of 3 inaccessible states and a state of the accessible one.

Not only a set of isolated states, but we also find states without any input or output transitions. This may be indicative of forgetfulness or inattention by those responsible for modeling the pathways.

4.2.4 Equivalent Transitions Evaluation

The algorithm to detect logically equivalent transitions is similar to that used to find non-determinism, but the results regarding performance are quite different. According to the table 9, which shows the performance of this algorithm, there is a small variation of the execution time for each pathway (see the full table in Appendix F). Pediatric Abdominal Pain pathway is among the 7 most time-consuming pathways to perform in all 4 algorithms, and in the equivalent

transitions detection algorithm it again took longer. The interesting thing about this pathway is that by adding the number of nodes created for the execution of the algorithms, we have only 368 nodes, a value much lower than the others that also take relatively high time.

Table 9 – Equivalent transitions algorithm evaluation.

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Pediatric Abdominal Pain	101	328	53,864577
(C) ACEI BBC Betablocker	3	155	23,398936
(H) Abdominal Pain	176	3260	13,458785
(H) Stroke	2	365	11,512536
(C) Joint Pain	25	77	6,732354
(C) Backache	9	202	4,438039
(H) Hypertensive Syndrome	21	85	4,210987
⋮	⋮	⋮	⋮
(C) Very High Risk Dyslipidemia Treatment	2	4	0,101513
(H) Pediatric Laryngitis	2	4	0,091063
(H) Exposed Fracture	2	4	0,087611
(C) FP UTI	1	2	0,060506
(H) Pediatric Septic Arthritis	1	2	0,056448
(H) Bandage	1	2	0,051409
(C) Verify Episode (UTI)	0	0	0,000792

Source: made by the author.

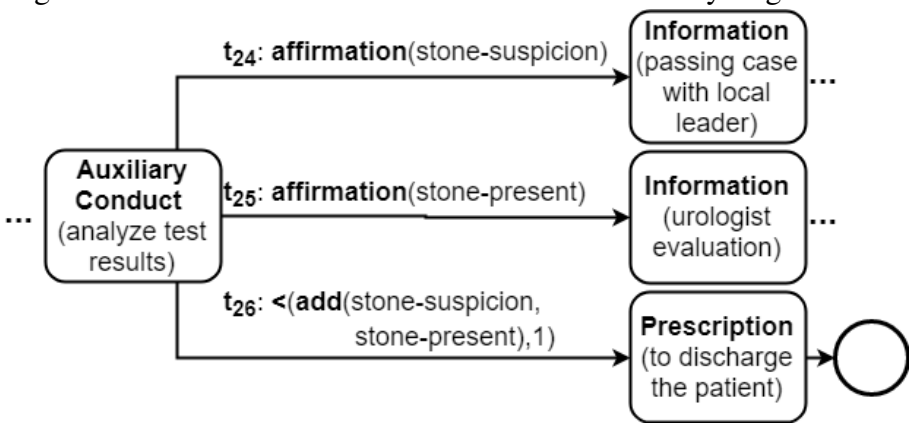
As can be seen from Table 4, there were no cases of equivalent transitions in any of the tested pathways. Although it may be interesting to verify the existence of equivalent transitions, it is a very specific case of non-determinism with little possibility of an incident, as it is a very straightforward verification that can be done at modeling time.

4.2.5 General Examples

To exemplify the problems found, Figure 11 shows a fragment of the Low Back Pain pathway that presents a problem of non-determinism. The *Auxiliary Conduct* has three transitions, the transitions t_{24} and t_{25} have different operands, *stone-suspicion* and *stone-present* respectively. If both operands assume the value *true* (*stone-suspicion* = 1 and *stone-present* = 1), then both transactions are valid (evaluate to true) and then we have a non-determinism problem, as it would not be possible to decide which step will be executed next. We can notice that in this case there is no deadlock problem, since transition t_{26} is always true when the other two transitions are false, *stone-suspicion* + *stone-present* = 0.

Another example that presents problems is the *exposed fracture* pathway in Figure 12. It is a small pathway with only four steps but presenting deadlock and non-determinism

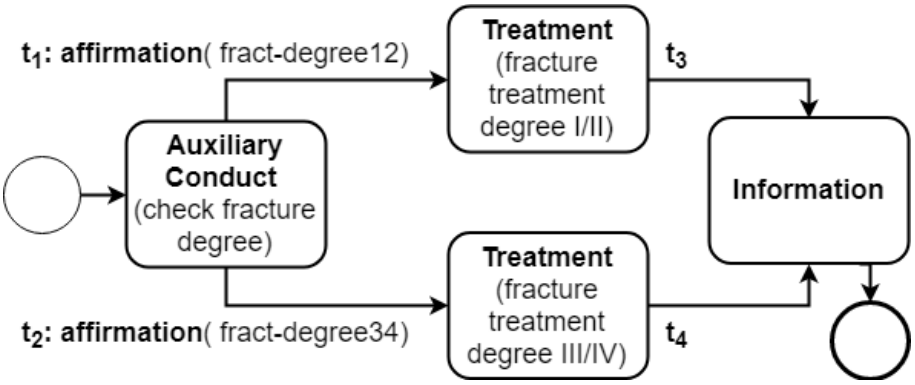
Figure 11 – Flowchart of Low Back Pain Care Pathway fragment.



Source: made by the author.

problems. It has two different operands, *fract-degree12* and *fract-degree34*, and both can assume true or false values at the same time.

Figure 12 – Flowchart of Exposed Fracture Care Pathway

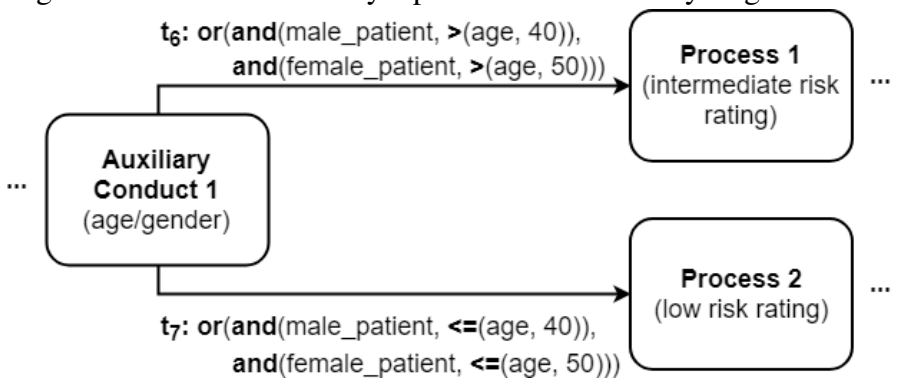


Source: made by the author.

Dyslipidemia pathway is another pathway with a state in deadlock and non-determinism situation but with some peculiar features. Figure 13 shows a fragment of this pathway with 3 states (*Auxiliary Conduct*, *Process 1* and *Process 2*), 2 transitions (t_6 and t_7) and 5 operands ($male\_patient$, $female\_patient$, age, 40 and 50). A deadlock problem is noticeable when the $male\_patient$ and $female\_patient$ take false values at the same time. The same would be true for non-determinism if these both variables were true with age between 40 and 50. However, If we execute the algorithms we find that state *Auxiliary Conduct* is in deadlock problems when $male\_patient = 0$, $female\_patient = 0$, $age = 0$, $40 = 0$ and $50 = 0$; and it is in a non-determinism problem when $male\_patient = 1$, $female\_patient = 1$, $age = 1$, $40 = 1$ and $50 = 0$.

In the results of the deadlock detection algorithm we have $40 = 0$ and $50 = 0$ and for the non-determinism one we have $40 = 1$ and $50 = 0$. While these valuations may seem

Figure 13 – Flowchart of Dyslipidemia Care Pathway fragment



Source: made by the author.

wrong, they are right. The problem is that operands 40 and 50 are not defined as constants but as Numeric variables within the pathway, named respectively "40" and "50", having no value previously assigned with them. Therefore the algorithms assign any integer values to these operands.

Based on the results, we can conclude that some of the problems are due to poor definition of variables. For instance, in Figure 12, instead of defining 2 boolean variables (fract-degree12 and fract-degree34), the modeler could have created one single numeric variable for expressing the degree of the fracture, in this way, we would avoid the problem of assigning true for both variables. The same goes for the case of Figure 13 which has 2 variables to define the patient's gender and two numeric operands whose values are assigned to their names.

All the results obtained with the execution of the algorithms in the set of tested pathways were analyzed manually and individually. Also, some pathways were redesigned and still run in real scenarios. Some models were built with deliberate errors to test the algorithms. However, it is hard to ensure that there are no more errors from the execution of the algorithms, as well as no false positives. An induction proof would be needed to guarantee that given any model as input, our algorithms would find all the errors. We are aware that our approach would benefit from such a theoretical proof and will investigate further in future work.

5 RELATED WORK

There are papers in the literature focusing on error detection in business process models (HAMMER, 2015; RGIBI *et al.*, 2011; STACKELBERG *et al.*, 2014; KABBAJ *et al.*, 2015; KHERBOUCHE *et al.*, 2012; AWAD; PUHLMANN, 2008; MARUTA *et al.*, 1998). Many of these papers try to find errors in the data-flow, such as missing, redundant or unused data, as can be seen in (RGIBI *et al.*, 2011), (STACKELBERG *et al.*, 2014) and (KABBAJ *et al.*, 2015). Also, there has been an effort to find structural errors as deadlocks and other problems in workflows (KHERBOUCHE *et al.*, 2012; AWAD; PUHLMANN, 2008; MARUTA *et al.*, 1998).

In (KHERBOUCHE *et al.*, 2012) Kherbouche, Ahmad and Basson propose an approach to automate the checking of some structural errors in BPMN process models (OMG, 2011) based on model checking. BPMN is a standard for process modeling that provides support for modelling control flow, data flow, and resource allocation. They map the BPMN process model to Kripke structures (BROWNE *et al.*, 1988) that provide semantics and allow checking the validity of a specific property holds or not. In our work, we bring this verification capacity closer to the clinical pathway domain by abstracting structures that are not familiar to stakeholders from the medical domain, such as gateways from the BPMN notation. Our algorithms are ready to check any process model that uses only boxes as steps and arrows as transitions between them.

There are also similar studies that analyze clinical pathways. In (WEBER *et al.*, 2017), the authors present a method for detecting execution paths in two Business Process models that violate a set of constraints. They extended BPMN to become more appropriate for modelling care pathways, and after, transformed this extended BPMN to CPN (Couloured Petri Nets) (JENSEN; KRISTENSEN, 2009), aiming to simplify the analysis since CPN is normally used when the process behavior is heavily influenced by the data to model concurrent systems by analyzing their properties. In the mentioned work, CPN models are enhanced with logical constraints to represent potential conflicts.

Another similar approach is the integrated framework developed in (BOWLES *et al.*, 2017) which detects and resolves conflicts in the pathways used for patients with multimorbidities. They also use BPMN to model the guidelines that is transformed into an intermediate formal model for a better analysis, then using a constraint solver Z3 (COK *et al.*, 2014) to check the satisfiability of a set of assertions expressed in first-order logic, together with the theorem prover Isabelle (NIPKOW *et al.*, 2002), a proof assistant which provides a framework to accommodate logical systems to compute the validity of logical deductions, to combine treatment plans

and check the correctness of the approach. Both papers have different objectives than the one presented in this work. The problem addressed in Weber's paper is to identify conflicts between clinical pathways when they are followed concurrently in treating patients with multiple morbidities. And Bowles' aims at finding a combination of formalisms able to capture pathways, highlighting the problems using an event-based approach.

Our approach focuses on the practice, by reading existing pathways as they are (drawing of boxes and arrows with labelled transitions) and calculating the existence of 4 problems, without requiring a previous formalization of the pathways in, for example, an event based system. Being closer to the practice, we are able to validate our approach within a real set of pathways and actually find modelling errors.

Therefore, the main contribution of this work is to present a set of algorithms to verify the bad construction of modeled care pathways without using well-known approaches that have, for example, scalability limitations, such as Petri Nets (DENARO; PEZZE, 2003). Besides, it contributes to the use, auditing and management of care pathways in a more practical way, as we do not consider verbose process languages to describe pathways, but rather a simplistic and powerful notation containing only states, transitions and guards. The verification of these pathways become straightforward; instead of having to translate pathways from practice to computer science modeling languages and then finding the formalism to map to, we simply get the already existing pathways and give as input to our approach

Table 10 shows the main features present in our work and which ones are also present in the works of Kherbouche, Weber and Bowles. The letter "X" means that the work uses the feature, and we use letter "O" when it does not use it.

Table 10 – Features used in the works.

Features	Our Work	Kherbouche	Weber	Bowles
Automated verification	X	X	X	X
Specific to medical field	X	O	X	X
DSL	X	O	O	O
CP Solver	X	O	O	X
Simplistic and powerful notation	X	X	O	O
Straightforward verification	X	O	O	O

Source: made by the author.
Note: X = Used Feature; O = Unused Feature.

According to Table 10, there are 2 features of our work that are not used by any of the 3 main works analyzed, DSL and straightforward verification. Thus, these two features become

the biggest differential of our work. The use of a DSL allows us to make a straightforward verification of care pathways, which makes the error checking process easier and faster for modelers.

6 CONCLUSION

This work offers a solution for finding possible logical problems in the structure of a clinical pathway. It contributes to the audit and management of these pathways, helping in the process of correction. The algorithms were tested in real pathways and we were able to find problems and report them accordingly. We believe that our approach may prevent serious mistakes that can ultimately affect patient's treatment.

We tested the algorithms in a dataset with 113 real clinical pathways and found several examples of pathways with deadlock, non-determinism, and inaccessible step problems. For the vast majority of pathways, detection algorithms performed in less than 1 second. Enough time for a developer who takes about 2 to 4 hours to model a care pathway with 10 states.

Interestingly, we realize that much of the deadlock and non-determinism errors are provided by the lack of well-defined variables. Many variables are created as Boolean to represent the existence or not of some physical, biological or psychological condition of the patient in order to simplify the pathway modeling; However, the guard conditions are sometimes created considering only the semantics of these variables' name, ignoring the mathematical logic and allowing the existence of deadlock or non-determinism.

Detecting inaccessible steps proved to be a great way to check isolated states from pathways, or even possibly not modeled transitions; because, as shown in Chapter 4, there are pathways with sets of states connected, but not connected by any set of transitions to the initial state.

As future work, we would like to investigate theoretical proofs for the correctness and completeness of our algorithms and also improve their performance. We may also address other possible pathway problems, such as the existence of cycles and data inconsistency caused by concurrent operations. Considering that some pathways were dropped from the dataset because they were out of the model, presented no connection transitions and logically wrong operations (e.g. a unary operator with more than one variable as an operand), it may be interesting to check beforehand if the pathways are according to the defined model. Thus avoiding possible problems to verify satisfiability. Finally, we have to embed these algorithms into the modeling practice, checking in real-time if a pathway under construction is correct. This allows a quick fix by the modeler before the pathway goes into use in the practice.

REFERENCES

ANONSEN, S. **UML Modeling Languages and Applications**. In: NUNES, N. J.; SELIC, B.; SILVA, A. Rodrigues da; ALVAREZ, A. T. (Ed.). Berlin, Heidelberg: Springer-Verlag, 2005. cap. Experiences in Modeling for a Domain Specific Language, p. 187–197. ISBN 3-540-25081-6. Disponível em: http://dl.acm.org/citation.cfm?id=2206963.2206984. Acesso em: 22 de fer. 2018.

AWAD, A.; PUHLMANN, F. Structural detection of deadlocks in business process models. In: ABRAMOWICZ, W.; FENSEL, D. (Ed.). **Business Information Systems**. Berlin, Germany: Springer, 2008. p. 239–250. ISBN 978-3-540-79396-0.

BAIER, C.; KATOEN, J.-P. **Principles of Model Checking (Representation and Mind Series)**. Cambridge, MA: The MIT Press, 2008. ISBN 026202649X, 9780262026499.

BAYINDIR, H.; KILIÇ, H.; REHAN, M. An agent-based trading infrastructure for combinatorial reverse auctions. In: **2014 IEEE Symposium on Intelligent Agents (IA)**. Orlando, FL, USA: IEEE, 2014. p. 38–44.

BOWLES, J.; CAMINATI, M. B.; CHA, S. An integrated framework for verifying multiple care pathways. In: **2017 International Symposium on Theoretical Aspects of Software Engineering (TASE)**. Sophia Antipolis, France: IEEE, 2017. p. 1–8.

BRASIL. Ministério da Saúde. **Protocolos Clínicos e Diretrizes Terapêuticas - PCDT**. Brasília, DF, 2014. Disponível em: http://bvsms.saude.gov.br/bvs/publicacoes/protocolos_clinicos_diretrizes_terapeuticas_v3.pdf. Acesso em: 17 fev. 2019. ISBN 9788533422070.

BROWNE, M.; CLARKE, E.; GRüMBERG, O. Characterizing finite kripke structures in propositional temporal logic. **Theoretical Computer Science**, v. 59, n. 1, p. 115 – 131, 1988. ISSN 0304-3975. Disponível em: http://www.sciencedirect.com/science/article/pii/0304397588900989. Acesso em: 7 mar. 2019.

CABALLERO, H. S. G.; CORVò, A.; DIXIT, P. M.; WESTENBERG, M. A. Visual analytics for evaluating clinical pathways. In: **2017 IEEE Workshop on Visual Analytics in Healthcare (VAHC)**. Phoenix, AZ, USA: IEEE, 2017. p. 39–46.

COK, D. R.; DÉHARBE, D.; WEBER, T. The 2014 SMT competition. **Journal on Satisfiability, Boolean Modeling and Computation**, v. 9, p. 207–242, 2014. Disponível em: http://user.it.uu.se/~tjawe125/publications/cok16the.pdf. Acesso em: 4 jun. 2019.

COSGROVE, L.; SHAUGHNESSY, A. F.; SHANEYFELT, T. When is a guideline not a guideline? the devil is in the details. **BMJ Evidence-Based Medicine**, Royal Society of Medicine, v. 23, n. 1, p. 33–36, 2018. ISSN 2515-446X. Disponível em: https://ebm.bmj.com/content/23/1/33. Acesso em: 12 set. 2018.

CPA. The effectiveness of care pathways in health and social care. **Centre for Policy on Ageing - Rapid Reviews**, May 2014.

DENARO, G.; PEZZE, M. Petri nets and software engineering. In: SPRINGER. **Advanced Course on Petri Nets**. Berlin, Heidelberg: Springer, 2003. p. 439–466.

DJULBEGOVIC, B.; GUYATT, G. H. Progress in evidence-based medicine: a quarter century on. **The Lancet**, Elsevier, v. 390, n. 10092, p. 415–423, Jul 2017. ISSN 0140-6736.

ELLIS, P. G.; O'NEIL, B. H.; EARLE, M. F.; MCCUTCHEON, S.; BENSON, H.; KREBS, M.; LOKAY, K.; BARRY, A. Clinical pathways: Management of quality and cost in oncology networks in the metastatic colorectal cancer setting. **Journal of Oncology Practice**, v. 13, n. 5, p. e522–e529, 2017. Disponível em: https://doi.org/10.1200/JOP.2016.019232. Acesso em: 17 fev. 2019.

EVANS-LACKO, S.; JARRETT, M.; MCCRONE, P.; THORNICROFT, G. Facilitators and barriers to implementing clinical care pathways. **BMC Health Services Research**, v. 10, n. 1, p. 182, Jun 2010. ISSN 1472-6963. Disponível em: https://doi.org/10.1186/1472-6963-10-182. Acesso em: 17 fev. 2019.

FRANCE, R.; RUMPE, B. Model-driven development of complex software: A research roadmap. In: **Future of Software Engineering, 2007. FOSE '07**. Minneapolis, MN, USA: IEEE, 2007. p. 37–54.

GOOCH, P.; ROUDSARI, A. Computerization of workflows, guidelines, and care pathways: a review of implementation challenges for process-oriented health information systems. **Journal of the American Medical Informatics Association**, BMJ Group, v. 18, n. 6, p. 738–748, 2011.

GOODWIN, S.; MEARS, C.; DWYER, T.; BANDA, M. G. de la; TACK, G.; WALLACE, M. What do constraint programming users want to see? exploring the role of visualisation in profiling of models and search. **IEEE Transactions on Visualization and Computer Graphics**, v. 23, n. 1, p. 281–290, Jan 2017. ISSN 1077-2626.

HAMMER, M. What is business process management? In: BROCKE, J. vom; ROSEMANN, M. (Ed.). **Handbook on Business Process Management 1: Introduction, Methods, and Information Systems**. Berlin, Heidelberg: Springer Berlin Heidelberg, 2015. p. 3–16. ISBN 978-3-642-45100-3. Disponível em: https://doi.org/10.1007/978-3-642-45100-3_1. Acesso em: 3 mar. 2018.

JENSEN, P.; KRISTENSEN, L. M. **Coloured Petri Nets: Modelling and Validation of Concurrent Systems**. 1. ed. Heidelberg, Germany: Springer-Verlag, 2009. ISBN 978-3-642-00284-7.

KABBAJ, M. I.; BÉTARI, A.; BAKKOURY, Z.; RHARBI, A. Towards an active help on detecting data flow errors in business process models. **International Journal on Computational Science & Applications**, v. 12, n. 1, p. 16–25, 2015.

KHERBOUCHE, O. M.; AHMAD, A.; BASSON, H. Detecting structural errors in bpmn process models. In: **2012 15th International Multitopic Conference (INMIC)**. Islamabad, Pakistan: IEEE, 2012. p. 425–431.

LOPEZ, J.; RAMIREZ, B. Cost savings through clinical care pathways in austria, poland, and the slovak republic. **Clinical Social Work and Health Intervention**, v. 8, n. 2, p. 38–43, 2017. Disponível em: https://www.clinicalsocialwork.eu/wp-content/uploads/2017/02/08-Lopez.pdf. Acesso em: 17 fev. 2019.

LOUËT, G. L.; MENAUD, J. M. Optiplace: Designing cloud management with flexible power models through constraint programing. In: **2013 IEEE/ACM 6th International Conference on Utility and Cloud Computing**. Dresden, Germany: IEEE, 2013. p. 211–218.

MARUTA, T.; ONODA, S.; IKKAI, Y.; KOBAYASHI, T.; KOMODA, N. A deadlock detection algorithm for business processes workflow models. In: **SMC'98 Conference Proceedings. 1998 IEEE International Conference on Systems, Man, and Cybernetics (Cat. No.98CH36218)**. San Diego, CA, USA: IEEE, 1998. v. 1, p. 611–616 vol.1. ISSN 1062-922X.

MILANO, M. Twenty years of constraint programming (cp) research. **Constraints**, v. 23, n. 2, p. 155–157, Apr 2018. ISSN 1572-9354. Disponível em: https://doi.org/10.1007/s10601-018-9284-7. Acesso em: 7 mar. 2019.

MOHAGHEGHI, P.; FERNANDEZ, M. A.; MARTELL, J. A.; FRITZSCHE, M.; GILANI, W. Mde adoption in industry: Challenges and success criteria. In: CHAUDRON, M. R. V. (Ed.). **Models in Software Engineering**. Berlin, Germany: Springer, 2009. p. 54–59. ISBN 978-3-642-01648-6.

MUSSBACHER, G.; AMYOT, D.; BREU, R.; BRUEL, J.-M.; CHENG, B. H. C.; COLLET, P.; COMBEMALE, B.; FRANCE, R. B.; HELDAL, R.; HILL, J.; KIENZLE, J.; SCHÖTTLE, M.; STEIMANN, F.; STIKKOLORUM, D.; WHITTLE, J. The relevance of model-driven engineering thirty years from now. In: DINGEL, J.; SCHULTE, W.; RAMOS, I.; ABRAHÃO, S.; INSFRAN, E. (Ed.). **Model-Driven Engineering Languages and Systems**. Cham: Springer International Publishing, 2014. p. 183–200.

MV. **Protocolo clínico: entenda a importância da gestão do conhecimento**. 2016. Disponível em: http://www.mv.com.br/pt/blog/protocolo-clinico--entenda-a-importancia-da-gestao-do-conhecimento#. Acesso em: 22 mar. 2018.

NIPKOW, T.; PAULSON, L. C.; WENZEL, M. **Isabelle/HOL: A Proof Assistant for Higher-Order Logic**. 1. ed. Heidelberg, Germany: Springer, 2002. ISBN 978-3-540-45949-1.

NOUASRIA, H.; ET-TOLBA, M. Compressive sensing via constraint programming. In: **2017 International Conference on Wireless Networks and Mobile Communications (WINCOM)**. Rabat, Morocco: IEEE, 2017. p. 1–6.

OMG. **Business Process Model and Notation (BPMN)**. Needham, MA, USA, 2011. Disponível em: https://www.omg.org/spec/BPMN/2.0/PDF. Acesso em: 11 abr. 2018.

PANELLA, M.; MARCHISIO, S.; STANISLAO, F. D. Reducing clinical variations with clinical pathways: do pathways work? **International Journal for Quality in Health Care**, v. 15, n. 6, p. 509–521, 2003. Disponível em: http://dx.doi.org/10.1093/intqhc/mzg057. Acesso em: 12 set. 2018.

POELMANS, J.; DEDENE, G.; VERHEYDEN, G.; MUSSELE, H. V. D.; VIAENE, S.; PETERS, E. Combining business process and data discovery techniques for analyzing and improving integrated care pathways. In: SPRINGER. **Industrial Conference on Data Mining**. Berlin, Germany: Springer, 2010. p. 505–517.

PRODEL, M. **Process discovery, analysis and simulation of clinical pathways using health-care data**. Tese (Doutorado) — Université de Lyon, 2017.

PRUD'HOMME, C.; FAGES, J.-G.; LORCA, X. **Choco Solver Documentation**. 2017. Disponível em: http://www.choco-solver.org. Acesso em: 16 dez. 2017.

RGIBI, A. E.; YAO, S. Z.; XU, J. J. Dataflow errors detection in business process model. **Applied Mechanics and Materials**, v. 130-134, 10 2011.

ROSSI, F.; BEEK, P. v.; WALSH, T. **Handbook of Constraint Programming (Foundations of Artificial Intelligence)**. New York, NY, USA: Elsevier Science Inc., 2006. ISBN 0444527265.

SCHMIDT, D. C. Guest editor's introduction: Model-driven engineering. **Computer**, v. 39, n. 2, p. 25–31, Feb 2006. ISSN 0018-9162.

SCHRIJVERS, G.; HOORN, A. van; HUISKES, N. The care pathway: concepts and theories: an introduction. **International journal of integrated care**, Ubiquity Press, v. 12, n. Special Edition Integrated Care Pathways, 2012.

SELIC, B. The pragmatics of model-driven development. **IEEE Software**, v. 20, n. 5, p. 19–25, Sept 2003. ISSN 0740-7459.

SHI, J.; SU, Q.; ZHAO, Z. Critical factors for the effectiveness of clinical pathway in improving care outcomes. In: **2008 International Conference on Service Systems and Service Management**. Melbourne, VIC, Australia: IEEE, 2008. p. 1–6. ISSN 2161-1890.

STACKELBERG, S. v.; PUTZE, S.; MüLLE, J.; BöHM, K. Detecting data-flow errors in bpmn 2.0. **Open Journal of Information Systems**, v. 1, n. 2, p. 1–19, 2014. ISSN 2198-9281.

VANHAECHT, K.; PANELLA, M.; ZELM, R. V.; SERMEUS, W. Is there a future for pathways? five pieces of the puzzle. **International Journal of Care Pathways**, v. 13, n. 2, p. 82–86, 2009. Disponível em: https://doi.org/10.1258/jicp.2009.009013. Acesso em: 12 set. 2018.

VANHAECHT, K.; PANELLA, M.; ZELM, R. van; SERMEUS, W. An overview on the history and concept of care pathways as complex interventions. **International Journal of Care Pathways**, v. 14, n. 3, p. 117–123, 2010. Disponível em: https://doi.org/10.1258/jicp.2010.010019. Acesso em: 22 mar. 2018.

VANHAECHT, K.; PANELLA, M.; ZELM, R. van; SERMEUS, W. What about care pathways? In: **Care of the Dying: A Pathway to Excellence**. Oxford, England: Oxford University Press, 2011. Disponível em: https://dx.doi.org/10.1093/acprof:oso/9780199550838.003.0001. Acesso em: 3 mar. 2018.

VANHAECHT, K.; WITTE, K. D.; SERMEUS, W. **The impact of clinical pathways on the organisation of care processes**. Tese (dissertation) — Katholieke Universiteit Leuven, 2007.

WEBER, P.; FILHO, J. B. F.; BORDBAR, B.; LEE, M.; LITCHFIELD, I.; BACKMAN, R. Automated conflict detection between medical care pathways. **Journal of Software: Evolution and Process**, v. 0, n. 0, p. e1898, 2017. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1002/smr.1898. Acesso em: 27 jan. 2018.

WENSING, M.; ELWYN, G. Methods for incorporating patients' views in health care. **BMJ**, BMJ Publishing Group Ltd, v. 326, n. 7394, p. 877–879, 2003. ISSN 0959-8138. Disponível em: https://www.bmj.com/content/326/7394/877.1. Acesso em: 17 fer. 2019.

ZANDER, K. Integrated care pathways: Eleven international trends. **Journal of integrated Care Pathways**, v. 6, n. 3, p. 101–107, 2002. Disponível em: https://doi.org/10.1177/147322970200600302. Acesso em: 17 fev. 2019.

GLOSSARY

– **Action:** triggers the change of state

– **Atomic proposition:** express simple known facts about the states of the system under consideration, formalizing temporal characteristics

– **BoolVar:** a boolean variables of Choco solver whose domain is $[0, 1]$. It can be used to say whether or not constraint should be satisfied as reification

– **Care pathway:** process-based guideline, a standardization, to assist health professionals with decision making when treating patients, sequencing the activities of the multidisciplinary health care team. Also named clinical pathway

– **Choco solver:** a free and open-source satisfaction problem solver software dedicated to Constraint Programming

– **Choice:** a kind of operand that is an integer variable composed by components called Option

– **Constraint:** a restriction over variables as a logic formula that must be satisfied in order to get a feasible solution

– **Constraint programming:** represents a real-world problem in terms of decision variables and constraints, and find an assignment to all the variables that satisfies the constraints

– **Contradiction:** set of logically incompatible propositions taken as truth, generating logical inversions, usually opposite each other

– **Data-dependent transition system:** a transition system where executable actions typically result from conditional branching, being a graph labeled with guard conditions

– **Deadlock:** a problem that occurs in a system when there is no satisfiable transition that allows it to evolve from one state into another

– **Equivalent transitions:** transitions with logically equivalent guard conditions which generates a situation of non-determinism

– **Guard condition:** a boolean expression composed by a set of variables that need to be satisfied to an action be performed. In this work it may also be called a transition operation

– **Inaccessible step:** a state that will never run in a pathway, an unreachable state

– **IntVar:** an integer variable of Choco whose domain is a set of integers representing possible values. Its domain could be bounded or enumerated

– **Labeling function:** relates a set of atomic propositions to any state, standing for exactly those atomic propositions which are satisfied by the state

– **Model:** the key component from Choco solver, used to declare variables and constraints
– **Model-driven engineering:** software development methodology that creates domain models that provides organized and structured methods for a number of perks such as code reuse, problem scope definition, ease of applicability
– **Non-determinism:** a problem that occurs in a system when there is more than one possible transition, make it unable to resolve the next state
– **Numeric:** a kind of operand that can be an integer constant or a variable whose domain is the set of integers $\mathbb{Z}$
– **Operand:** used in the care pathway. It is a variable or a constant that can be Numeric,YesOrNo, Choice or an operation
– **Operation:** it is the guard condition of a conditional transition in the care pathway. A set of operands related by an operator
– **Option:** a component from the Choice operand with a integer weight that is added to the operand's value when chosen
– **State:** describes some information about a system at a certain moment of its behavior. In this work as a step of a pathways. In this work it is also called the pathway's step
– **Transition:** specify how the system can evolve from one state to another. Also treated as a pathway's sequence
– **Transition system:** models to describe the behavior of systems, being basically directed graphs where nodes represent states, and edges model transitions
– **YesOrNo:** a kind of operand that represents a boolean variable whose domain is 0 or 1

APPENDIX A – CARE PATHWAYS DATASET

Table 11 – Care Pathways Dataset: continued

Pathway	States	Transitions	Paths
(H) Pediatric URTI	49	63	31
(H) Woman Abdominal Pain	43	45	22
(H) Pediatric Abdominal Pain	39	45	27
(C) Diabetes Treatment	38	53	15
(C) Diabetes Mellitus	38	53	15
(H) Chest Pain	38	44	30
(C) Allergic Rhinitis	36	35	27
(H) Abdominal Pain	36	49	24
(H) Pediatric Dermatological Disorders	34	36	27
(H) SIRS Treatment	32	40	16
(H) Childhood Wheezing	31	38	25
(H) UTI	29	29	13
(C) Joint Pain	28	38	20
(H) Hypertensive Syndrome	28	29	14
(H) Diarrhea	27	35	22
(H) Dermatological Disorders	26	28	19
(H) URTI	26	28	15
(C) LW Toxoplasmosis	25	28	10
(H) Pediatric Arboviruses	24	25	12
(C) Sinusitis	23	25	14
(H) Premature Amniorrexis	23	26	9
(H) Nausea and Vomiting	23	24	12
(H) Obstetric Nausea and Vomiting	23	24	12
(C) Hypothyroidism	22	30	13
(H) Heart Block	22	24	18
(C) Headache	21	26	40
(C) African Line Monotherapy	21	25	5
(C) Parasitosis	21	33	81
(H) Musculoskeletal Pain	21	20	10
(C) Backache	19	24	37
(C) African Line Tetratherapy	19	23	8
(H) Dizziness and Vertigo	19	19	10
(C) UTI	18	23	11
(H) Fever Without Location Signs	18	21	10
(H) Neonatal jaundice	18	19	9
(H) Community-Acquired Pneumonia	18	18	8
(C) Vulvovaginitis	17	21	16
(H) Dyspepsia	17	18	9

Table 12 – Care Pathways Dataset: continued

Pathway	States	Transitions	Paths
(H) Low Back Pain	17	16	10
(C) Pharyngitis	16	22	19
(C) Episode or Return (UTI)	16	18	15
(C) Acute Otitis Media	16	21	10
(C) Bar Tetratherapy	16	20	4
(H) Vaginal Discharge	16	16	11
(H) Obstetric Vaginal Discharge	16	16	11
(H) Herpes Virus Infection	16	16	10
(H) Earache	16	15	8
(H) Pneumonia Influenza	16	19	13
(H) Sepsis Treatment	16	23	11
(H) Deep Vein Thrombosis	16	18	11
(C) Cardiac Insufficiency	15	19	30
(C) LW Prematurity	15	14	6
(C) ACEI Line Monotherapy	14	17	4
(H) Pediatric Traumatic Brain Injury	14	19	15
(C) Acne	13	16	7
(C) Dyspepsia	13	14	8
(C) Temp Dyspepsia	13	14	8
(H) Headache	13	13	11
(H) Dengue	13	13	6
(H) Pediatric Gastroenteritis	13	17	13
(H) Systemic Arterial Hypertension	13	13	7
(C) Dyslipidemia	12	11	4
(C) Hyperkalemia	12	14	7
(C) FP Vertigo	12	13	7
(C) ACEI Line Tetratherapy	12	15	5
(H) Asthma	12	13	8
(H) Febrile Neutropenia	12	11	7
(H) Pediatric Sepsis	12	16	13
(C) African Line Doubletherapy	11	13	4
(C) FP Diarrhea	11	15	9
(C) Low Risk Dyslipidemia Treatment	11	13	8
(C) African Line Tripletherapy	11	13	4
(H) Pediatric Cellulitis	11	12	6
(H) COPD	11	12	6
(H) UTI in Pregnant Women	11	11	6
(H) Preterm Labor	11	10	11

Table 13 – Care Pathways Dataset: conclusion

Pathway	States	Transitions	Paths
(H) Pediatric Urticaria	11	14	8
(H) Postpartum Hemorrhage	10	11	7
(C) Hypertension II	9	8	5
(C) Hypertension Doublotherapy Bar	9	10	2
(C) High Risk Dyslipidemia Treatment	9	9	4
(C) Intermediary Risk Dyslipidemia Treatment	9	9	4
(C) Very High Risk Dyslipidemia Treatment	9	9	4
(H) Stroke	9	8	3
(H) Chikungunya	9	8	4
(H) Pediatric Conjunctivitis	9	8	4
(H) Diabetes Mellitus	9	8	4
(H) Cardiac Insufficiency	9	9	5
(C) Syphilis	8	10	4
(H) Pulmonary Embolism	8	7	4
(C) Diabetes Insulin Therapy	7	9	4
(C) ACEI Line Doubletherapy	7	8	2
(C) Hypertension Monotherapy Bar	7	8	2
(C) Hypertension Tripletherapy Bar	7	8	2
(C) Kidney Transplant	7	6	3
(H) Meningitis	7	9	4
(H) Zika	7	6	3
(C) BAR BBC Betablocker	6	4	3
(C) FP UTI	6	5	2
(C) ACEI Line Tripletherapy	6	7	2
(H) Ophthalmologic Disorders	6	6	5
(H) Prolonged Gestation	6	5	3
(H) High Digestive Bleeding	6	5	3
(H) Pediatric Laryngitis	6	6	3
(C) African American Pharmacological	5	4	3
(H) Exposed Fracture	5	4	3
(H) Check Sepsis	5	5	4
(C) ACEI BBC Betablocker	4	3	3
(H) Pediatric Septic Arthritis	4	3	2
(H) Check Arbovirus	4	3	3
(H) Bandage	3	2	2
(H) Puerperal Endometritis	3	2	2
(C) Verify Episode (UTI)	1	0	1

Source: made by the author.

APPENDIX B – CARE PATHWAYS AND THE FOUND PROBLEMS

Table 14 – The pathways and the found problems: continued

Pathway	Dl	ND	IS	ET	BT	N	Time (ms)
(H) Stroke	2	0	0	0	13	25198162	900631,2377
(C) Hypothyroidism	1	2	0	0	44	8141877	133349,094
(H) Pneumonia Influenza	0	0	0	0	25	135356	2935,423889
(H) Pediatric Abdominal Pain	1	0	0	0	140	368	1681,503843
(C) Headache	3	3	0	0	52	8531	114,279475
(C) ACEI BBC Betablocker	1	0	0	0	10	415	62,81959
(C) Backache	1	1	0	0	34	1420	54,823821
(C) Joint Pain	3	8	0	0	64	173	40,978017
(H) Hypertensive Syndrome	8	1	4	0	55	151	26,052605
(C) Allergic Rhinitis	7	8	1	0	127	942	25,886946
(H) Abdominal Pain	2	1	1	0	230	3655	20,578904
(H) Pediatric URTI	4	1	0	0	89	146	20,109778
(H) Deep Vein Thrombosis	1	2	0	0	29	81	19,382811
(C) Parasitosis	2	2	0	0	73	728	18,058844
(C) Pharyngitis	1	1	0	0	31	426	13,517798
(C) Dyspepsia	1	0	0	0	20	370	11,985112
(C) Temp Dyspepsia	1	0	0	0	20	370	11,954462
(H) Pediatric Arboviruses	3	0	0	0	38	61	10,443937
(C) UTI	3	2	0	0	38	170	10,260224
(H) Chest Pain	2	2	0	0	81	356	9,502325
(H) URTI	2	2	0	0	56	221	8,81795
(C) Episode or Return (UTI)	0	0	0	0	28	441	8,699922
(H) UTI	2	1	0	0	43	152	8,643334
(H) Woman Abdominal Pain	4	2	0	0	103	407	8,572237
(C) Diabetes Mellitus	3	3	0	0	61	83	7,833186
(H) Pediatric Traumatic Brain Injury	2	1	0	0	26	42	7,64812
(C) Diabetes Treatment	3	3	0	0	61	83	7,468886
(H) Pediatric Dermatological Disorders	8	3	0	0	128	659	7,396343
(H) Diarrhea	5	2	0	0	65	159	7,390884
(H) Dermatological Disorders	3	3	0	0	88	488	7,084384
(C) Hyperkalemia	0	1	0	0	18	104	7,002931
(C) FP Diarrhea	1	1	0	0	22	280	6,694239
(H) Dizziness and Vertigo	3	0	0	0	36	70	6,687336
(H) Low Back Pain	1	1	0	0	49	117	6,291636
(H) Febrile Neutropenia	0	0	0	0	23	141	6,195536
(H) Childhood Wheezing	7	0	0	0	56	121	6,189097
(H) Earache	3	1	0	0	28	80	6,176875
(H) Chikungunya	1	0	0	0	12	19	5,216136

Table 15 – The pathways and the found problems: continued

Pathway	Dl	ND	IS	ET	BT	N	Time (ms)
(H) Dyspepsia	0	0	0	0	22	155	4,679785
(H) Dengue	2	0	0	0	19	51	4,610601
(C) Acne	2	2	0	0	23	34	4,51254
(H) Heart Block	7	1	0	0	45	77	4,315065
(C) Sinusitis	2	3	0	0	60	228	4,189899
(H) High Digestive Bleeding	1	1	0	0	9	47	4,130838
(C) Dyslipidemia	1	1	0	0	16	59	3,941433
(H) Obstetric Vaginal Discharge	6	0	0	0	37	67	3,773443
(H) Herpes Virus Infection	1	2	0	0	33	85	3,513315
(H) Community-Acquired Pneumonia	4	0	0	0	29	46	3,290787
(H) Vaginal Discharge	6	0	0	0	37	67	3,204435
(C) Cardiac Insufficiency	1	3	0	0	37	129	3,129933
(H) Headache	2	1	0	0	27	69	3,08081
(H) COPD	1	0	0	0	17	52	3,076703
(H) Obstetric Nausea and Vomiting	1	1	0	0	80	560	3,063129
(H) Nausea and Vomiting	1	1	0	0	80	560	3,052911
(H) SIRS Treatment	1	1	0	0	75	321	3,046846
(H) Pulmonary Embolism	1	0	0	0	11	22	3,029165
(C) African Line Monotherapy	1	1	0	0	27	58	2,981861
(H) Meningitis	0	0	0	0	13	42	2,852871
(C) Acute Otitis Media	2	2	0	0	25	48	2,837241
(H) Sepsis Treatment	1	1	0	0	71	549	2,821426
(H) Neonatal jaundice	4	0	0	0	31	47	2,746879
(C) African Line Tetratherapy	1	1	0	0	25	54	2,721827
(C) FP Vertigo	2	2	0	0	19	98	2,716134
(H) Premature Amniorrexis	2	2	3	0	34	51	2,668598
(C) LW Toxoplasmosis	0	0	0	0	30	36	2,540772
(H) Pediatric Sepsis	1	1	0	0	24	111	2,434828
(H) Ophthalmologic Disorders	1	0	0	0	13	38	2,419106
(H) Zika	0	0	0	0	8	11	2,401752
(C) African Line Doubletherapy	1	1	0	0	15	34	1,993365
(H) Preterm Labor	2	0	2	0	26	57	1,972046
(H) Asthma	1	1	1	0	17	22	1,966728
(H) Pediatric Urticaria	1	0	0	0	16	28	1,910139
(C) Vulvovaginitis	2	2	0	0	31	50	1,845854
(H) Musculoskeletal Pain	2	2	0	0	55	220	1,770419
(H) Fever Without Location Signs	1	1	0	0	29	43	1,769251
(H) Systemic Arterial Hypertension	2	1	0	0	24	41	1,74294

Table 16 – The pathways and the found problems: conclusion

Pathway	Dl	ND	IS	ET	BT	N	Time (ms)
(C) African Line Tripletherapy	1	1	0	0	15	34	1,667318
(H) UTI in Pregnant Women	3	0	3	0	16	29	1,583813
(H) Pediatric Cellulitis	1	0	0	0	17	25	1,531375
(H) Check Sepsis	0	0	0	0	12	32	1,518128
(C) LW Prematurity	0	0	0	0	19	24	1,503479
(C) BAR BBC Betablocker	0	0	1	0	6	8	1,497881
(C) Bar Tetratherapy	0	0	0	0	20	24	1,48995
(H) Pediatric Gastroenteritis	2	2	0	0	28	56	1,470917
(C) Kidney Transplant	1	1	0	0	11	24	1,463545
(C) ACEI Line Monotherapy	0	0	0	0	17	21	1,44092
(C) Hypertension II	0	0	0	0	12	16	1,308057
(C) ACEI Line Tetratherapy	0	0	0	0	16	20	1,193293
(H) Cardiac Insufficiency	1	0	0	0	16	28	1,179485
(H) Pediatric Conjunctivitis	2	0	0	0	14	21	1,161197
(C) Low Risk Dyslipidemia Treatment	1	1	0	0	18	28	1,141884
(C) Diabetes Insulin Therapy	0	0	0	0	9	11	1,140719
(H) Diabetes Mellitus	1	0	0	0	13	19	1,046388
(H) Postpartum Hemorrhage	1	1	0	0	15	19	1,017325
(C) Hypertension Doublotherapy Bar	0	0	0	0	10	12	0,925235
(H) Prolonged Gestation	1	0	0	0	8	13	0,9104
(C) Syphilis	0	0	0	0	11	14	0,891694
(C) Very High Risk Dyslipidemia Treatment	0	0	0	0	10	12	0,780802
(C) ACEI Line Doubletherapy	0	0	0	0	8	10	0,763588
(C) Hypertension Monotherapy Bar	0	0	0	0	8	10	0,746793
(C) Hypertension Tripletherapy Bar	0	0	0	0	8	10	0,734011
(H) Puerperal Endometritis	0	0	0	0	3	7	0,693424
(C) High Risk Dyslipidemia Treatment	0	0	0	0	10	12	0,693005
(C) Intermediary Risk Dyslipidemia Treatment	0	0	0	0	10	12	0,683628
(C) ACEI Line Tripletherapy	0	0	0	0	7	9	0,649899
(C) African American Pharmacological	0	0	0	0	6	8	0,537749
(H) Check Arbovirus	1	0	0	0	7	12	0,50388
(H) Exposed Fracture	1	1	0	0	8	10	0,486292
(H) Pediatric Septic Arthritis	0	0	0	0	4	5	0,461148
(H) Pediatric Laryngitis	0	0	0	0	7	9	0,442721
(C) FP UTI	0	0	0	0	6	7	0,408945
(H) Bandage	0	0	0	0	3	4	0,281306
(C) Verify Episode (UTI)	0	0	0	0	0	0	0,010588

Source: made by the author.

APPENDIX C – DEADLOCK EVALUATION

Table 17 – Deadlock Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(C) Hypothyroidism	4	4186157	72003,59365
(H) Pneumonia Influenza	1	67558	1583,499031
(H) Pediatric Abdominal Pain	1	2	68,817559
(C) Headache	7	4092	61,656245
(C) ACEI BBC Betablocker	1	128	22,153111
(C) Backache	2	546	18,420906
(C) Joint Pain	3	13	12,604225
(H) Stroke	2	105	6,566182
(C) Pharyngitis	2	130	6,308014
(C) Dyspepsia	2	146	5,19883
(C) Temp Dyspepsia	2	146	5,170373
(C) Allergic Rhinitis	8	91	5,011105
(H) Hypertensive Syndrome	8	18	3,64156
(C) Episode or Return (UTI)	1	147	3,462792
(C) Diabetes Mellitus	3	3	3,202151
(C) Acne	2	2	3,021656
(C) UTI	3	14	2,882076
(C) Diabetes Treatment	3	3	2,853058
(H) Febrile Neutropenia	2	19	2,437208
(C) Hyperkalemia	1	6	2,402499
(C) Parasitosis	2	14	2,225131
(C) FP Diarrhea	2	68	2,187017
(H) Pediatric URTI	4	8	2,136073
(H) Pediatric Dermatological Disorders	8	13	2,107336
(C) Dyslipidemia	1	9	2,037685
(H) Pediatric Arboviruses	3	6	1,897638
(H) Pediatric Traumatic Brain Injury	2	3	1,742382
(H) URTI	3	4	1,707534
(H) Deep Vein Thrombosis	1	2	1,616657
(H) UTI	2	3	1,419741
(H) Chest Pain	2	2	1,349624
(H) High Digestive Bleeding	1	2	1,337122
(H) Dermatological Disorders	3	3	1,315056
(H) Woman Abdominal Pain	4	6	1,311836
(H) Diarrhea	5	8	1,26985
(H) Abdominal Pain	2	3	1,241999
(H) Community-Acquired Pneumonia	4	8	1,193995
(C) Acute Otitis Media	2	8	1,068409

Table 18 – Deadlock Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(C) BAR BBC Betablocker	0	0	1,057167
(H) Low Back Pain	1	2	1,017979
(H) Dyspepsia	0	0	0,962231
(H) Dengue	2	4	0,939699
(H) Chikungunya	1	2	0,938112
(H) Childhood Wheezing	7	14	0,920478
(H) Dizziness and Vertigo	3	12	0,915207
(H) Earache	3	5	0,899765
(C) Sinusitis	2	2	0,876719
(H) Obstetric Vaginal Discharge	6	12	0,87546
(H) Premature Amniorrexis	2	2	0,840518
(H) Vaginal Discharge	6	12	0,825542
(C) FP Vertigo	2	11	0,819804
(H) Ophthalmologic Disorders	1	2	0,816912
(C) Cardiac Insufficiency	1	3	0,7725
(H) COPD	2	3	0,737791
(C) LW Toxoplasmosis	0	0	0,708867
(H) Herpes Virus Infection	1	1	0,704529
(H) Heart Block	7	15	0,690813
(C) African Line Monotherapy	1	4	0,684795
(C) African Line Doubletherapy	1	4	0,640056
(H) Neonatal jaundice	4	8	0,634085
(H) Headache	2	4	0,593265
(C) Hypertension II	0	0	0,552912
(C) Diabetes Insulin Therapy	0	0	0,551886
(C) African Line Tetratherapy	1	4	0,547127
(H) Meningitis	1	4	0,521562
(C) LW Prematurity	0	0	0,520629
(H) SIRS Treatment	1	1	0,503741
(C) ACEI Line Monotherapy	0	0	0,501409
(H) Pediatric Sepsis	1	1	0,496417
(H) UTI in Pregnant Women	3	6	0,491612
(C) African Line Tripletherapy	1	4	0,479669
(H) Pediatric Cellulitis	1	2	0,471458
(C) Kidney Transplant	2	5	0,469966
(H) Fever Without Location Signs	1	1	0,464134
(H) Pulmonary Embolism	1	2	0,455317
(H) Systemic Arterial Hypertension	2	3	0,448879

Table 19 – Deadlock Algorithm Evaluation: conclusion

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Check Sepsis	2	3	0,429659
(C) Vulvovaginitis	2	2	0,406193
(H) Zika	0	0	0,399242
(H) Obstetric Nausea and Vomiting	1	1	0,394997
(H) Pediatric Urticaria	1	2	0,390658
(H) Nausea and Vomiting	1	1	0,386086
(H) Preterm Labor	2	4	0,384687
(H) Pediatric Gastroenteritis	2	2	0,381281
(C) Hypertension Doublotherapy Bar	0	0	0,367099
(C) Low Risk Dyslipidemia Treatment	1	1	0,360335
(C) ACEI Line Tetratherapy	0	0	0,342934
(H) Asthma	1	1	0,340275
(C) Hypertension Tripletherapy Bar	0	0	0,330198
(C) ACEI Line Doubletherapy	0	0	0,324273
(H) Musculoskeletal Pain	2	2	0,323574
(C) Bar Tetratherapy	0	0	0,321754
(C) Hypertension Monotherapy Bar	0	0	0,319515
(H) Pediatric Conjunctivitis	2	4	0,319468
(H) Postpartum Hemorrhage	1	1	0,306639
(C) Syphilis	0	0	0,289192
(H) Cardiac Insufficiency	1	2	0,283313
(H) Prolonged Gestation	1	2	0,27445
(H) Sepsis Treatment	1	1	0,270857
(C) Very High Risk Dyslipidemia Treatment	0	0	0,266192
(H) Puerperal Endometritis	0	0	0,26204
(C) High Risk Dyslipidemia Treatment	0	0	0,242634
(H) Diabetes Mellitus	1	2	0,24156
(C) Intermediary Risk Dyslipidemia Treatment	0	0	0,233863
(C) ACEI Line Tripletherapy	0	0	0,216742
(C) African American Pharmacological	0	0	0,19267
(H) Exposed Fracture	1	1	0,19099
(C) FP UTI	0	0	0,187025
(H) Pediatric Laryngitis	0	0	0,134916
(H) Check Arbovirus	1	2	0,129411
(H) Bandage	0	0	0,115835
(H) Pediatric Septic Arthritis	0	0	0,114622
(C) Verify Episode (UTI)	0	0	0,001539

Source: made by the author.

APPENDIX D – NON-DETERMINISM EVALUATION

Table 20 – Non-Determinism Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Stroke	1	25197558	900609,5035
(C) Hypothyroidism	6	3955244	61333,98003
(H) Pneumonia Influenza	1	67558	1344,124234
(H) Pediatric Abdominal Pain	0	0	55,26104
(C) Headache	10	4086	45,728482
(C) ACEI BBC Betablocker	3	72	14,170265
(C) Backache	5	458	11,348696
(C) Joint Pain	9	17	7,45853
(H) Hypertensive Syndrome	3	10	3,653036
(C) Allergic Rhinitis	24	162	3,016198
(C) Pharyngitis	4	79	2,609398
(C) Dyspepsia	2	124	2,283118
(C) Episode or Return (UTI)	1	156	2,165417
(C) Temp Dyspepsia	2	124	2,143304
(H) Abdominal Pain	18	324	2,032087
(C) Parasitosis	9	98	1,965096
(H) Pediatric Arboviruses	0	0	1,902956
(C) UTI	5	22	1,815718
(H) Pediatric Traumatic Brain Injury	2	4	1,79995
(H) Deep Vein Thrombosis	2	3	1,530772
(H) Pediatric Dermatological Disorders	13	89	1,470218
(H) Pediatric URTI	1	1	1,414563
(C) FP Diarrhea	3	71	1,251143
(H) URTI	7	22	1,185364
(C) Diabetes Mellitus	4	6	1,150423
(H) Chikungunya	0	0	1,129056
(H) Woman Abdominal Pain	10	58	1,109556
(H) Diarrhea	5	13	1,105731
(H) Dermatological Disorders	12	72	1,040885
(C) Diabetes Treatment	4	6	1,039066
(H) Obstetric Vaginal Discharge	0	0	1,017466
(H) Chest Pain	7	41	1,002118
(H) High Digestive Bleeding	1	7	0,995913
(H) Febrile Neutropenia	1	17	0,992228
(H) Asthma	1	1	0,972308
(H) Childhood Wheezing	0	0	0,969042
(H) UTI	1	1	0,941938
(H) Dizziness and Vertigo	0	0	0,930695

Table 21 – Non-Determinism Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(C) Hyperkalemia	1	10	0,926216
(C) Sinusitis	9	38	0,828948
(H) Heart Block	1	1	0,703736
(H) Low Back Pain	1	1	0,66912
(H) Earache	2	4	0,644862
(H) Dengue	0	0	0,634365
(H) SIRS Treatment	7	49	0,621069
(C) Acne	3	5	0,591726
(H) Community-Acquired Pneumonia	0	0	0,581416
(H) Vaginal Discharge	0	0	0,572832
(C) Cardiac Insufficiency	6	25	0,545587
(H) Obstetric Nausea and Vomiting	9	81	0,534298
(H) Premature Amniorrexis	3	5	0,529773
(H) Dyspepsia	0	0	0,529353
(H) Nausea and Vomiting	9	81	0,520629
(H) Pediatric Sepsis	3	21	0,492872
(H) Herpes Virus Infection	4	10	0,489186
(H) Sepsis Treatment	9	81	0,488253
(H) Neonatal jaundice	0	0	0,487647
(C) Dyslipidemia	1	6	0,473091
(H) Headache	3	9	0,460729
(C) African Line Doubletherapy	1	2	0,440762
(H) Meningitis	0	0	0,432738
(H) Ophthalmologic Disorders	0	0	0,427233
(C) Acute Otitis Media	2	4	0,42532
(H) Pulmonary Embolism	0	0	0,423267
(H) COPD	0	0	0,419909
(C) African Line Tetratherapy	1	2	0,390192
(C) FP Vertigo	2	11	0,386366
(H) Preterm Labor	0	0	0,356463
(C) African Line Monotherapy	1	2	0,352031
(H) Check Sepsis	2	2	0,347506
(H) Systemic Arterial Hypertension	2	4	0,34284
(C) Vulvovaginitis	4	7	0,342281
(H) Zika	0	0	0,330245
(H) UTI in Pregnant Women	0	0	0,329685
(H) Musculoskeletal Pain	8	40	0,317882
(C) LW Toxoplasmosis	0	0	0,316389

Table 22 – Non-Determinism Algorithm Evaluation: conclusion

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Fever Without Location Signs	2	4	0,30272
(H) Pediatric Urticaria	0	0	0,294836
(C) Kidney Transplant	1	2	0,265306
(C) African Line Tripletherapy	1	2	0,254016
(H) Pediatric Cellulitis	0	0	0,251077
(H) Pediatric Gastroenteritis	4	10	0,249678
(C) Hypertension II	0	0	0,245899
(H) Cardiac Insufficiency	0	0	0,244873
(C) LW Prematurity	0	0	0,242074
(C) Bar Tetratherapy	0	0	0,237595
(C) ACEI Line Tetratherapy	0	0	0,225512
(H) Pediatric Septic Arthritis	0	0	0,218841
(H) Diabetes Mellitus	0	0	0,217255
(C) Hypertension Doublotherapy Bar	0	0	0,199994
(C) Low Risk Dyslipidemia Treatment	2	4	0,198595
(H) Pediatric Conjunctivitis	0	0	0,195375
(C) ACEI Line Monotherapy	0	0	0,192343
(H) Postpartum Hemorrhage	1	1	0,187025
(H) Prolonged Gestation	0	0	0,17205
(C) ACEI Line Doubletherapy	0	0	0,162673
(C) Syphilis	0	0	0,162067
(C) BAR BBC Betablocker	0	0	0,158241
(C) Diabetes Insulin Therapy	0	0	0,144386
(H) Puerperal Endometritis	0	0	0,136175
(C) Very High Risk Dyslipidemia Treatment	0	0	0,133842
(C) Hypertension Monotherapy Bar	0	0	0,133049
(C) Hypertension Tripletherapy Bar	0	0	0,129131
(C) High Risk Dyslipidemia Treatment	0	0	0,122646
(H) Check Arbovirus	0	0	0,115508
(C) Intermediary Risk Dyslipidemia Treatment	0	0	0,114342
(C) ACEI Line Tripletherapy	0	0	0,11103
(C) African American Pharmacological	0	0	0,107671
(H) Pediatric Laryngitis	0	0	0,087331
(H) Exposed Fracture	1	1	0,082572
(C) FP UTI	0	0	0,06144
(H) Bandage	0	0	0,049404
(C) Verify Episode (UTI)	0	0	0,000886

Source: made by the author.

APPENDIX E – INACCESSIBLE STEP EVALUATION

Table 23 – Inaccessible Step Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Pediatric Abdominal Pain	38	38	1503,560667
(C) Backache	18	214	20,61618
(H) Pediatric URTI	48	55	15,032336
(H) Hypertensive Syndrome	23	38	14,547022
(H) Deep Vein Thrombosis	15	34	14,495192
(C) Joint Pain	27	66	14,182908
(C) Allergic Rhinitis	34	289	13,938174
(C) Parasitosis	20	78	9,65777
(C) Hypothyroidism	21	376	9,238794
(H) Pneumonia Influenza	15	195	6,331526
(H) Chest Pain	37	135	5,852089
(C) Headache	20	279	5,43414
(H) Pediatric Arboviruses	23	29	5,389028
(H) UTI	28	111	5,298571
(H) URTI	25	105	4,687811
(H) Woman Abdominal Pain	42	66	4,248215
(H) Earache	15	51	4,05783
(H) Diarrhea	26	55	4,033572
(C) UTI	17	59	3,894037
(H) Abdominal Pain	34	68	3,846033
(C) Temp Dyspepsia	12	72	3,693436
(H) Stroke	8	134	3,655415
(C) Dyspepsia	12	72	3,632416
(C) Pharyngitis	15	158	3,554882
(H) Low Back Pain	16	16	3,53025
(H) Dizziness and Vertigo	18	19	3,493302
(H) Childhood Wheezing	30	63	3,191374
(C) ACEI BBC Betablocker	3	60	3,097278
(H) Dermatological Disorders	25	55	3,014332
(C) Diabetes Treatment	37	37	2,774498
(H) Dyspepsia	16	136	2,695563
(C) Diabetes Mellitus	37	37	2,694957
(C) FP Diarrhea	10	106	2,530277
(H) Chikungunya	8	11	2,501447
(C) Hyperkalemia	11	54	2,47089
(C) Episode or Return (UTI)	16	106	2,419667
(H) Dengue	12	30	2,414255
(H) Pediatric Traumatic Brain Injury	13	13	2,352722

Table 24 – Inaccessible Step Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Heart Block	21	22	2,093201
(H) Febrile Neutropenia	11	66	1,823976
(H) Herpes Virus Infection	15	31	1,78017
(H) Pulmonary Embolism	7	13	1,701142
(C) African Line Monotherapy	20	40	1,621462
(H) Pediatric Dermatological Disorders	33	33	1,488692
(C) African Line Tetratherapy	18	36	1,48384
(H) Headache	12	16	1,483001
(H) COPD	10	37	1,471524
(C) Sinusitis	22	55	1,450018
(H) Meningitis	6	12	1,374723
(H) Zika	6	7	1,338988
(H) Obstetric Vaginal Discharge	15	15	1,27139
(C) LW Toxoplasmosis	24	24	1,228097
(H) Vaginal Discharge	15	15	1,226278
(C) Cardiac Insufficiency	14	28	1,21065
(C) FP Vertigo	11	61	1,177387
(H) Neonatal jaundice	17	17	1,176035
(H) Community-Acquired Pneumonia	17	20	1,040372
(H) High Digestive Bleeding	5	25	1,029922
(C) Dyslipidemia	11	33	0,991855
(H) Pediatric Urticaria	10	16	0,902051
(C) Acute Otitis Media	15	20	0,893
(H) Premature Amniorrexis	19	19	0,869955
(H) SIRS Treatment	31	31	0,846769
(H) Pediatric Sepsis	11	44	0,814673
(C) Vulvovaginitis	16	16	0,744509
(H) Ophthalmologic Disorders	5	12	0,737511
(C) Bar Tetratherapy	16	16	0,725475
(H) Preterm Labor	8	8	0,718338
(C) African Line Tripletherapy	10	20	0,700983
(C) African Line Doubletherapy	10	20	0,696318
(H) Fever Without Location Signs	17	17	0,672899
(H) Nausea and Vomiting	22	22	0,611226
(C) Acne	12	12	0,591679
(H) Obstetric Nausea and Vomiting	22	22	0,577637
(C) ACEI Line Monotherapy	13	13	0,547407
(H) Pediatric Gastroenteritis	12	12	0,543302

Table 25 – Inaccessible Step Algorithm Evaluation: conclusion

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Systemic Arterial Hypertension	12	12	0,535651
(C) LW Prematurity	14	14	0,528
(H) Musculoskeletal Pain	20	20	0,520023
(H) Sepsis Treatment	15	15	0,513351
(C) Kidney Transplant	6	11	0,512931
(H) Pediatric Cellulitis	10	10	0,495297
(H) Asthma	10	10	0,443841
(C) ACEI Line Tetratherapy	12	12	0,443094
(H) Pediatric Conjunctivitis	8	8	0,43633
(H) UTI in Pregnant Women	7	8	0,420935
(H) Diabetes Mellitus	8	8	0,403721
(H) Cardiac Insufficiency	8	8	0,385387
(C) Low Risk Dyslipidemia Treatment	10	10	0,361734
(C) Hypertension II	8	8	0,343494
(H) Postpartum Hemorrhage	9	9	0,337616
(H) Check Sepsis	4	9	0,322594
(C) Diabetes Insulin Therapy	7	7	0,318862
(H) Prolonged Gestation	5	6	0,290218
(C) Syphilis	8	8	0,288025
(C) Very High Risk Dyslipidemia Treatment	8	8	0,279255
(C) Intermediary Risk Dyslipidemia Treatment	8	8	0,229711
(C) High Risk Dyslipidemia Treatment	8	8	0,222107
(C) Hypertension Doublotherapy Bar	8	8	0,214923
(C) ACEI Line Tripletherapy	5	5	0,206992
(C) Hypertension Monotherapy Bar	6	6	0,175315
(C) ACEI Line Doubletherapy	6	6	0,171164
(C) BAR BBC Betablocker	4	4	0,167944
(C) Hypertension Tripletherapy Bar	6	6	0,165612
(H) Puerperal Endometritis	2	5	0,156841
(H) Check Arbovirus	3	3	0,133143
(C) African American Pharmacological	4	4	0,129924
(H) Pediatric Laryngitis	5	5	0,129411
(H) Exposed Fracture	4	4	0,125119
(C) FP UTI	5	5	0,099974
(H) Pediatric Septic Arthritis	3	3	0,071237
(H) Bandage	2	2	0,064658
(C) Verify Episode (UTI)	0	0	0,007371

Source: made by the author.

APPENDIX F – EQUIVALENT TRANSITIONS EVALUATION

Table 26 – Equivalent Transitions Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Pediatric Abdominal Pain	101	328	53,864577
(C) ACEI BBC Betablocker	3	155	23,398936
(H) Abdominal Pain	176	3260	13,458785
(H) Stroke	2	365	11,512536
(C) Joint Pain	25	77	6,732354
(C) Backache	9	202	4,438039
(H) Hypertensive Syndrome	21	85	4,210987
(C) Parasitosis	42	538	4,210847
(C) Allergic Rhinitis	61	400	3,921469
(H) Pediatric Dermatological Disorders	74	524	2,330097
(C) Hypothyroidism	13	100	2,281532
(H) Woman Abdominal Pain	47	277	1,90263
(H) Pediatric Traumatic Brain Injury	9	22	1,753066
(H) Deep Vein Thrombosis	11	42	1,74019
(H) Dermatological Disorders	48	358	1,714111
(C) UTI	13	75	1,668393
(H) Obstetric Nausea and Vomiting	48	456	1,556197
(H) Sepsis Treatment	46	452	1,548965
(H) Nausea and Vomiting	48	456	1,53497
(H) Pediatric URTI	36	82	1,526806
(H) Pneumonia Influenza	8	45	1,469098
(C) Headache	15	74	1,460608
(H) Dizziness and Vertigo	15	39	1,348132
(H) Chest Pain	35	178	1,298494
(H) Pediatric Arboviruses	12	26	1,254315
(H) URTI	21	90	1,237241
(C) Hyperkalemia	5	34	1,203326
(H) Childhood Wheezing	19	44	1,108203
(H) SIRS Treatment	36	240	1,075267
(H) Low Back Pain	31	98	1,074287
(C) Pharyngitis	10	59	1,045504
(C) Sinusitis	27	133	1,034214
(H) UTI	12	37	0,983084
(H) Diarrhea	29	83	0,981731
(C) Temp Dyspepsia	4	28	0,947349
(H) Febrile Neutropenia	9	39	0,942124
(C) Dyspepsia	4	28	0,870748
(H) Heart Block	16	39	0,827315

Table 27 – Equivalent Transitions Algorithm Evaluation: continued

Pathway	Binary Trees	Nodes	Runtime (ms)
(C) Diabetes Treatment	17	37	0,802264
(C) Diabetes Mellitus	17	37	0,785655
(H) High Digestive Bleeding	2	13	0,767881
(C) FP Diarrhea	7	35	0,725802
(C) Episode or Return (UTI)	10	32	0,652046
(H) Chikungunya	3	6	0,647521
(H) Pediatric Sepsis	9	45	0,630866
(H) Dengue	5	17	0,622282
(H) Obstetric Vaginal Discharge	16	40	0,609127
(H) Musculoskeletal Pain	25	158	0,60894
(C) Cardiac Insufficiency	16	73	0,601196
(H) Vaginal Discharge	16	40	0,579783
(H) Earache	8	20	0,574418
(H) Headache	10	40	0,543815
(H) Herpes Virus Infection	13	43	0,53943
(H) Meningitis	6	26	0,523848
(H) Preterm Labor	16	45	0,512558
(H) Dyspepsia	6	19	0,492638
(H) Community-Acquired Pneumonia	8	18	0,475004
(C) Acute Otitis Media	6	16	0,450512
(H) Pulmonary Embolism	3	7	0,449439
(H) Neonatal jaundice	10	22	0,449112
(H) COPD	5	12	0,447479
(C) Dyslipidemia	3	11	0,438802
(H) Ophthalmologic Disorders	7	24	0,43745
(H) Premature Amniorrexis	10	25	0,428352
(H) Check Sepsis	4	18	0,418369
(H) Systemic Arterial Hypertension	8	22	0,41557
(C) Vulvovaginitis	9	25	0,352871
(H) UTI in Pregnant Women	6	15	0,341581
(H) Zika	2	4	0,333277
(C) FP Vertigo	4	15	0,332577
(H) Fever Without Location Signs	9	21	0,329498
(C) African Line Monotherapy	5	12	0,323573
(H) Pediatric Urticaria	5	10	0,322594
(H) Pediatric Cellulitis	6	13	0,313543
(C) Acne	6	15	0,307479
(C) African Line Tetratherapy	5	12	0,300668

Table 28 – Equivalent Transitions Algorithm Evaluation: conclusion

Pathway	Binary Trees	Nodes	Runtime (ms)
(H) Pediatric Gastroenteritis	10	32	0,296656
(C) LW Toxoplasmosis	6	12	0,287419
(H) Cardiac Insufficiency	7	18	0,265912
(C) African Line Tripletherapy	3	8	0,23265
(C) Low Risk Dyslipidemia Treatment	5	13	0,22122
(C) African Line Doubletherapy	3	8	0,216229
(C) Kidney Transplant	2	6	0,215342
(C) LW Prematurity	5	10	0,212776
(H) Asthma	5	10	0,210304
(H) Pediatric Conjunctivitis	4	9	0,210024
(C) Bar Tetratherapy	4	8	0,205126
(C) ACEI Line Monotherapy	4	8	0,199761
(H) Postpartum Hemorrhage	4	8	0,186045
(H) Diabetes Mellitus	4	9	0,183852
(C) ACEI Line Tetratherapy	4	8	0,181753
(H) Prolonged Gestation	2	5	0,173682
(C) Hypertension II	4	8	0,165752
(C) Syphilis	3	6	0,15241
(C) Hypertension Doublotherapy Bar	2	4	0,143219
(H) Puerperal Endometritis	1	2	0,138368
(H) Check Arbovirus	3	7	0,125818
(C) Diabetes Insulin Therapy	2	4	0,125585
(C) Hypertension Monotherapy Bar	2	4	0,118914
(C) ACEI Line Tripletherapy	2	4	0,115135
(C) BAR BBC Betablocker	2	4	0,114529
(C) Hypertension Tripletherapy Bar	2	4	0,10907
(C) African American Pharmacological	2	4	0,107484
(C) Intermediary Risk Dyslipidemia Treatment	2	4	0,105712
(C) High Risk Dyslipidemia Treatment	2	4	0,105618
(C) ACEI Line Doubletherapy	2	4	0,105478
(C) Very High Risk Dyslipidemia Treatment	2	4	0,101513
(H) Pediatric Laryngitis	2	4	0,091063
(H) Exposed Fracture	2	4	0,087611
(C) FP UTI	1	2	0,060506
(H) Pediatric Septic Arthritis	1	2	0,056448
(H) Bandage	1	2	0,051409
(C) Verify Episode (UTI)	0	0	0,000792

Source: made by the author.

APPENDIX G – DEADLOCK FOUND

- (C) ACEI BBC Betablocker
  - Auxiliary Conduct: Valores PS e PD
    - valor_ps=1, 130=0, 159=0, valor_pd=1, 80=0, 99=0, 160=0, 179=1, 100=2, 109=0
- (C) Acne
  - Auxiliary Conduct: Classificar Acne Grau I
    - predominio_comedonico=0, papulo_pustuloso=0
  - Auxiliary Conduct: Classificação do Grau de Severidade
    - grau_i=0, grau_ii=0, grau_iii=0
- (C) Acute Otitis Media
  - Auxiliary Conduct: Escolher tratamento: Adulto
    - opcao_tratamento_adulto=0, UM=1, DOIS=1
  - Auxiliary Conduct: Escolher tratamento: Pediátrico
    - opcao_tratamento_pediatrico=0, UM=1, DOIS=1
- (C) African Line Doubletherapy
  - Auxiliary Conduct: Verificar Medicação
    - medicacao_linha_duplo_afro=0, UM=1, DOIS=1
- (C) African Line Monotherapy
  - Auxiliary Conduct: Selecionar Medicação
    - selecionar_medicacao_mono_linha_afro=0, UM=1, DOIS=1
- (C) African Line Tetratherapy
  - Auxiliary Conduct: Verificação de Medicação
    - medicacao_linha_tetra_afro=0, DOIS=1, UM=1
- (C) African Line Tripletherapy
  - Auxiliary Conduct: Verificação de Medicação
    - medicacao_linha_triplo_afro=0, UM=1, DOIS=1
- (C) Allergic Rhinitis
  - Auxiliary Conduct: [Rinite Persistente] Idade
    - rin_pers_6_a_11_meses=0, rin_pers_12_meses_a_2_anos=0, rin_pers_2_a_5_anos=0, rin_pers_6_a_11-_anos=0, rin_pers_12_anos_a_adulto=0
  - Auxiliary Conduct: [Rinite Persisntente] Peso
    - rin_pers_2_a_5_anos=1, rin_pers_peso=1, 2=0, 1=0, rin_pers_6_a_11_anos=1, rin_pers_12_anos_a_-adulto=1
  - Auxiliary Conduct: Classificação da Rinite
    - classificacao_rinite=0, 1=1, 3=1, 4=1, 2=1
  - Auxiliary Conduct: [Rinite Intermitente] Idade
    - rin_interm_6_a_11_meses=0, rin_interm_11_meses_a_2_anos=0, rin_interm_2_a_5_anos=0, rin_interm-_6_a_11_anos=0, rin_interm_12_anos_adulto=0
  - Auxiliary Conduct: [Rinite Leve, Persistente ou Grave] Peso
    - rin_leve_2_a_5_anos=1, rinite_leve_peso=1, 1=0, 2=0, rin_leve_6_a_11_anos=1, rin_leve_acima_de_12-_anos=1
  - Auxiliary Conduct: [Rinite Intermitente] Peso
    - rin_interm_2_a_5_anos=1, rin_interm_peso=1, 2=0, 1=0, rin_interm_6_a_11_anos=1, rin_interm_12_-anos_adulto=1
  - Auxiliary Conduct: [Rinite Leve, Moderada ou Grave] Idade
    - rin_leve_6_a_11_meses=0, rin_leve_12_meses_2_anos=0, rin_leve_2_a_5_anos=0, rin_leve_6_a_11_a-

nos=0, rin_leve_acima_de_12_anos=0

- (C) Backache
  - Auxiliary Conduct: Classificação da Intensidade da Dor
    - classificacao_leve_moderada=0, classificacao_dor_severa=0, classificacao_dor_aguda_com_espasmos=0
- (C) Cardiac Insufficiency
  - Auxiliary Conduct: Classificar Estágio e Classe da Insuficiência Cardíaca
    - estagio_b=1, classe_1=0, classe_2=0, estagio_c=1, classe_3=0, classe_4=0, estagio_a=0
- (C) Diabetes Mellitus
  - Auxiliary Conduct: Escolher Monoterapia
    - monoterapia_opcao1=0, monoterapia_opcao2=0
  - Auxiliary Conduct: Escolher Duploterapia
    - duploterapia_opcao1=0, duploterapia_opcao2=0
  - Auxiliary Conduct: Nível de HbA1c
    - nivel_hba1c_menor_7_5=0, nivel_hba1c_entre_7_e_9=0, nivel_hba1c_maior_9=0
- (C) Diabetes Treatment
  - Auxiliary Conduct: Escolher Monoterapia
    - monoterapia_opcao1=0, monoterapia_opcao2=0
  - Auxiliary Conduct: Escolher Duploterapia
    - duploterapia_opcao1=0, duploterapia_opcao2=0
  - Auxiliary Conduct: Nível de HbA1c
    - nivel_hba1c_menor_7_5=0, nivel_hba1c_entre_7_e_9=0, nivel_hba1c_maior_9=0
- (C) Dyslipidemia
  - Auxiliary Conduct: Idade/Sexo
    - paciente_sexo_masculino=0, paciente_idade=0, 40=0, paciente_sexo_feminino=0, 50=0
- (C) Dyspepsia
  - Auxiliary Conduct: Risco de Dispepsias Funcional e/ou Orgânica
    - dispepcia_funcional_tabagismo=0, dispepcia_funcional_transtorno_psicologico=1, 1=5, risco_dispepcia_organica_uso_cronico_aines=0, risco_dispepcia_organica_tabagismo=1, risco_dispepcia_organica_antecedente_ulcera=0, risco_dispepcia_organica_ulcera_familia=0, risco_dispepcia_organica_patologias_cronicas=1, risco_dispepcia_organica_infeccap_helicobacter=1, risco_dispepcia_organica_longo_tempo=1
- (C) FP Diarrhea
  - Auxiliary Conduct: Reavaliar Sinais e Sintomas
    - sinais_sintomas_paciente=0, UM=1, DOIS=1, TRES=1
- (C) FP Vertigo
  - Auxiliary Conduct: Classificar Vertigem
    - vertigem_intensa=1, nistagmo_horizontal=1, nistagmo_fatigavel=1, tinitus_ou_hipocacusia=1, 2=5, vertigem_branda=1, nistagmo_ataxico=1, nistagmo_nao_fatigavel=0, outros_sintomas_neurologicos=1
  - Auxiliary Conduct: Classificar Vertigem Posicional
    - vertigem_posicional_meniere=0, vertigem_posicional_vppb=0
- (C) Headache
  - Auxiliary Conduct: Avaliar se houve melhora
    - resposta_satisfatoria_tratamento=0, piora_sintomas=0, acometimento_neurologico=0
  - Auxiliary Conduct: Realizar Avaliação para Cefaléia Primária
    - paciente_enxaqueca=0, paciente_cefaleia_tensional=0, paciente_outro_tipo_cefaleia=0
  - Auxiliary Conduct: Prescrever tratamento
    - tratamento_crise_enxaqueca=0, tratamento_cefaleia_tensional_cronica=0, tratamento_outros_tipos_cefa-

leia=0

- (C) Hypothyroidism
  - Auxiliary Conduct: Critérios de encaminhamento
    - encaminhamento_menor_18_anos=0, encaminhamento_tratamento_sem_resposta=0, encaminhamento_bocio_ou_nodulo=0, encaminhamento_hipotireoidismo_secundario=0, encaminhamento_hipertireoidismo=0, encaminhamento_gestante=0, encaminhamento_menor_18_anos=0, encaminhamento_tratamento_sem_resposta=0, encaminhamento_gestante=0, encaminhamento_bocio_ou_nodulo=0, encaminhamento_hipotireoidismo_secundario=0, encaminhamento_hipertireoidismo=0, 1=0
- (C) Joint Pain
  - Auxiliary Conduct: [Inflamatória] Monoarticular ou Poliarticular?
    - mono_ou_poliarticular=0, 1=1, 2=1
  - Auxiliary Conduct: [Monoarticular] Aguda ou Crônica?
    - monoarticular_dor_aguda_ou_cronica=0, 2=1, 1=1
  - Auxiliary Conduct: [Poliarticular] Aguda ou Crônica?
    - dor_poliarticular=0, 2=1, 1=1, 3=1
- (C) Kidney Transplant
  - Auxiliary Conduct: Verificar sexo do paciente
    - sexo_paciente=0, 1=1, 2=1
- (C) Low Risk Dyslipidemia Treatment
  - Auxiliary Conduct: Selecionar Terapia
    - terapia_medicação=0, terapia_mudanca_estilo_vida=0, terapia_medicacal_avulsa=0
- (C) Parasitosis
  - Auxiliary Conduct: Sinais e Sintomas
    - paras_sinais_sintomas=0, UM=1, TRES=1, DOIS=1, OITO=1, QUATRO=1, SETE=1, CINCO=1, SEIS=1, NOVE=1
  - Auxiliary Conduct: Condições de encaminhamento (Urgência)
    - condicoes_encaminhamento=0, UM=0, DOIS=0
- (C) Pharyngitis
  - Auxiliary Conduct: Definir encaminhamentos
    - imc_irregular=0, 7_ou_mais_episodios=0, suspeita_difteria=1
- (C) Sinusitis
  - Auxiliary Conduct: Diagnóstico Diferencial
    - corpos_estranhos_nasais=0, atresia_de_coana_unilateral=0, rinite_alergica=0, adenoidite=0
  - Auxiliary Conduct: [Sinusite] Avaliação do Quadro
    - sinusite_Aguda=0, sinusite_complicada=0, sinusite_cronica=0, sinusite_recorrente=0, outras_doencas=0
- (C) Temp Dyspepsia
  - Auxiliary Conduct: Risco de Dispepsias Funcional e/ou Orgânica
    - dispepcia_funcional_tabagismo=0, dispepcia_funcional_transtorno_psicologico=1, 1=5, risco_dispepcia_organica_uso_cronico_aines=0, risco_dispepcia_organica_tabagismo=1, risco_dispepcia_organica_antecedente_ulcera=0, risco_dispepcia_organica_ulcera_familia=0, risco_dispepcia_organica_patologias_cronicas=1, risco_dispepcia_organica_infeccap_helicobacter=1, risco_dispepcia_organica_longo_tempo=1
- (C) UTI
  - Auxiliary Conduct: [Recém nascido] Sintomas
    - recem_nascido_sintomas=1, 10=0
  - Auxiliary Conduct: [Retorno] Avaliar paciente
    - avaliar_paciente=0, 1=1, 2=1, 3=1

  - Auxiliary Conduct: Avaliar idade
    - faixa_etaria=0, 1=1, 2=1, 3=1, 4=1
- (C) Vulvovaginitis
  - Auxiliary Conduct: Consulta de Retorno
    - vulvovaginite_recorrente=0, resolucao_do_quadro_clinico=0, paciente_hiv_positiva=0
  - Auxiliary Conduct: Verificar Sinais e Sintomas
    - candidiase=0, vaginose_bacteriana=0, tricomoniase=0
- (H) Abdominal Pain
  - Auxiliary Conduct: Classificar suspeita conforme dor
    - obstucao_intestinal=0, pancreatite_aguda=0, nefrolitíase=0, apendicite_aguda=0, colecistite_aguda=0, diverticulite_aguda=0, doenca_inflamatoria_pelvica=0, ulcera_gastrica=0, dor_apos_trauma=0, torcao_do_ovario=0, colangite_aguda=0, aneurisma_aorta_abdominal=0, dispepsia_drge=0, gravidez_ectopica=0, infarto_mesenterico=0, hernia_abdominal=0, diagnostico_inconclusivo=0, dor_abdominal_simples=0, mais_de_duas_ocorrencias=0
  - Auxiliary Conduct: [Hérnia Abdominal] Avaliar hérnia
    - tipo_hernia=0
- (H) Asthma
  - Auxiliary Conduct: Avaliar Intensidade da Crise
    - crise_leve=0, crise_moderada_ou_grave=0
- (H) Cardiac Insufficiency
  - Auxiliary Conduct: Investigar Sintomas
    - congestao_perfusao=0
- (H) Check Arbovirus
  - Auxiliary Conduct: Avaliar tipo de arbovirose
    - tipo_arbovirose=0
- (H) Chest Pain
  - Auxiliary Conduct: Caracterização da Dor Torácica
    - dor_tipo_A=0, dor_tipo_B=0, dor_tipo_C=0, dor_tipo_D=0
  - Auxiliary Conduct: Procurar outras causas
    - outras_causas_pneumonia=0, outras_causas_tep_pneumotorax=0, outras_causas_disseccao=0, outras_causas_pericardite=0, outras_causas_drge_espasmo_esofagiano=0, outras_cauasas_dor_musculo_esqueletica=0, outras_causas_dor_psicogenica=0
- (H) Chikungunya
  - Auxiliary Conduct: Definir fase
    - fase_doenca=0
- (H) Childhood Wheezing
  - Auxiliary Conduct: [> 2 anos] Verificar sintomas
    - >2anos_quadro_paciente=0
  - Auxiliary Conduct: [< 2 anos] Verificar sintomas
    - <2anos_quadro_paciente=0
  - Auxiliary Conduct: [Corpos estranhos] Avaliar exame
    - corpos_estranhos_alteracao_imagem=0
  - Auxiliary Conduct: Avaliar Resposta
    - resposta_tratamento=0
  - Auxiliary Conduct: [BVA] Avaliar alteração
    - bva_alteracao=0
  - Auxiliary Conduct: Avaliar Intensidade da Crise

        * intensidade_crise=0
    - Auxiliary Conduct: [BVA] Avaliar saturação
        * bva_saturacao=0
- (H) Community-Acquired Pneumonia
    - Auxiliary Conduct: Avaliar Exames
        * nivel_alteracao_radiologica=0
    - Auxiliary Conduct: Avaliar quadro
        * sinais_de_alarme=0
    - Auxiliary Conduct: [Retorno] Avaliar
        * retorno_avaliar=0
    - Auxiliary Conduct: Avaliar exames
        * exames_laboratoriais=0
- (H) COPD
    - Auxiliary Conduct: Avaliar Resposta
        * resposta_a_medicacao=0
- (H) Deep Vein Thrombosis
    - Auxiliary Conduct: Escore de Wells
        * tep=0, escore_wells=0, 0=1
- (H) Dengue
    - Auxiliary Conduct: Avaliar Hemograma
        * hematocrito=0
    - Auxiliary Conduct: Avaliar Hemograma (2)
        * hematocrito_2=0
- (H) Dermatological Disorders
    - Auxiliary Conduct: [Afecções das Unhas] Sintomas
        * unha_encravada_sem_infeccao=0, onicomicose=0, unha_encravada_com_infeccao=0
    - Auxiliary Conduct: Avaliação do Quadro
        * celulite=0, urticaria=0, impetigo=0, pe_diabetico=0, escabiose=0, queimaduras=0, afeccoes_das_unhas-=0, cispo_pilonidal=0, abcesso_cutaneo=0
    - Auxiliary Conduct: Definir Grau da Queimadura
        * queimadura_grau_i=0, queimadura_grau_ii=0, queimadura_grau_iii=0
- (H) Diabetes Mellitus
    - Auxiliary Conduct: Classificar cenário do paciente diabético
        * estado_do_paciente=0
- (H) Diarrhea
    - Auxiliary Conduct: [Grupo B] Reavaliar paciente
        * semsinais_semdesidratacao=0, comsinais_semdesidratacao=0, semsinais_comdesidratacao=0, comsinais-_comdesidratacao=0
    - Auxiliary Conduct: Avaliar paciente
        * grupo_paciente=0
    - Auxiliary Conduct: [Grupo A] Sinais de Gravidade
        * grupoA_sinais_gravidade=0
    - Auxiliary Conduct: [Grupo B com Diarreia Cronica] Avaliar exames e melhora
        * semalteracoes_commelhora=0, semalteracoes_semmelhora=0, comalteracoes=0
    - Auxiliary Conduct: [Grupo B] Sinais de Gravidade
        * grupoB_sinais_gravidade=0
- (H) Dizziness and Vertigo

  - Auxiliary Conduct: Classificar como Tontura ou Vertigem
    - tontura=1, vertigem=1
  - Auxiliary Conduct: [Ménière] Classificar quadro
    - fase_aguda=1, meniere_fase_subaguda_ou_cronica=1
  - Auxiliary Conduct: Classificar suspeita de doença
    - vertigem_posicional_paroxistica_benigna=0, neurite_vestibular=1, doenca_de_meniere=0, mastoidite_-envolvimento_labirinto=1, trauma=0
- (H) Earache
  - Auxiliary Conduct: Classificar Quadro de Otalgia
    - acometimento_pavilhao_auricular=0, otite_externa=0, otite_media=0
  - Auxiliary Conduct: Classificar Otite Média
    - otite_media_aguda=1, otite_media_cronica=1
  - Treatment: Medicação para dor
    - acometimento_pavilhao_auricular=0, otite_media=0, otite_externa=0
- (H) Exposed Fracture
  - Auxiliary Conduct: Verificar Grau da Fratura
    - frat-grau12=0, frat-grau34=0
- (H) Fever Without Location Signs
  - Auxiliary Conduct: Avaliar Idade
    - idade_menor_28_ddv=0, idade_1_a_3_meses=0, idade_maior_3_meses=0
- (H) Headache
  - Auxiliary Conduct: Avaliar Sintomas/Sinais de Gravidade
    - sintomas=0, cefaleia_primaria=0
  - Auxiliary Conduct: [Cefaleia Primaria] Classificar Cefaleia
    - cefaleia_primaria_tensional=0, cefaleia_primaira_em_salvas=0, cefaleia_primaria_enxaqueca=0, retor-no=0
- (H) Heart Block
  - Auxiliary Conduct: Verificar idade gestacional
    - idade_gestacional_pp=0
  - Auxiliary Conduct: [>= 20 sem] Avaliar sinais
    - sinais=0
  - Auxiliary Conduct: [Sinais de infecção] Confirmar infecção
    - confirmar_infeccao=0
  - Auxiliary Conduct: Avaliar idade gestacional
    - idade_gestacional=0
  - Auxiliary Conduct: [Sinais de SFA] Confirmar
    - sinais_sfa=0
  - Auxiliary Conduct: Confirmar infecção
    - confirmar_infeccao_apos_exames=0, confirmar_infeccao=0
  - Auxiliary Conduct: [TP] Idade Gestacional
    - tp_idade_gestacional=0
- (H) Herpes Virus Infection
  - Auxiliary Conduct: Avaliação do Quadro
    - herpes_genital=0, herpes_labial=0, herpes_zoster=0, varicela=0
- (H) High Digestive Bleeding
  - Auxiliary Conduct: Marcador de Risco
    - glasgow_ureia=0, glasgow_hemoglobina_homem=0, glasgow_pas=0, glasgow_pulso=0, glasgow_me-

lena=0, glasgow_sincope=0, glasgow_doenca_hepatica=0, glasgow_insuficiencia_cardiaca=0, zero=1, glasgow_hemoglobina_mulher=0

- (H) Hypertensive Syndrome
  - Auxiliary Conduct: [PA = 140] Avaliar uso de medicação
    - pa140_uso_medicacao=0
  - Auxiliary Conduct: [PA = 140] Avaliar exames
    - pa140_exames=0
  - Auxiliary Conduct: Avaliar Idade Gestacional (Inicial)
    - idade_gestacional=0
  - Auxiliary Conduct: [<20 sem] Avaliar pressão
    - menor20_pressao=0
  - Auxiliary Conduct: [Puerpério] Avaliar exames
    - puerperio_exames=0
  - Auxiliary Conduct: [PA > 150 e < 160] Avaliar exames
    - pa150_160_exames=0
  - Auxiliary Conduct: [IG >= 20] Avaliar Quadro
    - maior20_pressao=0, maior20_sinais_cronicos=0, maior20_exames_laboratoriais=0, maior20_usg=0
  - Auxiliary Conduct: [Puerpério] Avaliar quadro
    - pressao_puerperio=0, avaliar_quadro_puerperio_novo=0
- (H) Low Back Pain
  - Auxiliary Conduct: Classificar quadro do paciente
    - quadro_paciente=0
- (H) Musculoskeletal Pain
  - Auxiliary Conduct: Monoartrite Aguda
    - artrite_septica=0, artrite_gotosa=0, artrite_pos_traumatica=0
  - Auxiliary Conduct: Classificar Dor
    - monoartrite=0, oligo_ou_poliartrite=0, artrite_cronica=0, artralgia_osteoartrose=0, trauma_musculoesqueletico=0, tendinite_tendossino_epicondi_bucite_dort=0, trauma_com_fratura_ou_limitacao=0
- (H) Nausea and Vomiting
  - Auxiliary Conduct: Sintomas do Paciente
    - emese_gravidica=0, cefaleia_nauseas_vomitos=0, dor_abdominal_nauseas_vomitos=0, dor_toracico_nauseas_vomitos=0, diarreia_nauseas_vomitos=0, dor_lombar_nauseas_vomitos=0, tontura_nauseas_vomitos=0, tratamento_quimioterapico_nauseas_vomitos=0, ingestao_alcool_nauseas_vomitos=0, sem_causa_aparente_nauseas_vomitos=0
- (H) Neonatal jaundice
  - Auxiliary Conduct: Verificar tempo de vida
    - tempo_vida=0
  - Auxiliary Conduct: Avaliar ultrassom
    - resultado_ultrassom=0
  - Auxiliary Conduct: Avaliar exames
    - resultado_exames=0
  - Auxiliary Conduct: Avaliar resultado
    - fototerapia=0
- (H) Obstetric Nausea and Vomiting
  - Auxiliary Conduct: Sintomas do Paciente
    - emese_gravidica=0, cefaleia_nauseas_vomitos=0, dor_abdominal_nauseas_vomitos=0, dor_toracico_nauseas_vomitos=0, diarreia_nauseas_vomitos=0, dor_lombar_nauseas_vomitos=0, tontura_nauseas_-

vomitos=0, tratamento_quimioterapico_nauseas_vomitos=0, ingestao_alcool_nauseas_vomitos=0, sem_-causa_aparente_nauseas_vomitos=0

- (H) Obstetric Vaginal Discharge
  - Auxiliary Conduct: Verificar tipo do corrimento da gestante
    - tipo_corrimento_gestante=0
  - Auxiliary Conduct: Quantidade de episódios
    - qtd_episodios=0
  - Auxiliary Conduct: Verificar tipo do corrimento da não gestante
    - tipo_corrimento_n_gestante=0
  - Auxiliary Conduct: Verificar gravidez
    - gravidez=0
  - Auxiliary Conduct: Classificar aspectos do corrimento da gestante
    - corrimento_patologico_gestante=0
  - Auxiliary Conduct: Classificar aspectos do corrimento da não gestante
    - corrimento_patologico_n_gestante=0
- (H) Ophthalmologic Disorders
  - Auxiliary Conduct: Diagnosticar paciente
    - diagnostico=0
- (H) Pediatric Abdominal Pain
  - Auxiliary Conduct: [Sem irritação peritoneal] Avaliar foco
    - sem_irrit_avaliar_foco=0
- (H) Pediatric Arboviruses
  - Auxiliary Conduct: [Chikungunya] Avaliar fase
    - ckya_fase=0
  - Auxiliary Conduct: Avaliar tipo de arbovirose
    - tipo_arbovirose=0
  - Auxiliary Conduct: [Dengue] Grupo B - Avaliar Primeiros Exames
    - dengue_grupob_hemograma01=0
- (H) Pediatric Cellulitis
  - Auxiliary Conduct: Classificar celulite
    - tipo_celulite=0
- (H) Pediatric Conjunctivitis
  - Auxiliary Conduct: Avaliar Hiperemia Conjuntival
    - hiperemia_conjuntival=0
  - Auxiliary Conduct: Avaliar Sintomas
    - sintomas=0
- (H) Pediatric Dermatological Disorders
  - Auxiliary Conduct: [Afecções das Unhas] Sintomas
    - unha_encravada_sem_infeccao=0, onicomicose=0, unha_encravada_com_infeccao=0
  - Auxiliary Conduct: [Dermatites] Avaliar
    - tipo_dermatite=0
  - Auxiliary Conduct: Avaliação do Quadro
    - celulite=0, urticaria=0, impetigo=0, queimaduras=0, afeccoes_das_unhas=0, cispo_pilonidal=0, abcesso-_cutaneo=0, dermatites=0, micoses=0, parasitoses=0
  - Auxiliary Conduct: Definir Grau da Queimadura
    - queimadura_grau_i=0, queimadura_grau_ii=0, queimadura_grau_iii=0
  - Auxiliary Conduct: [Parasitoses] Avaliar

        * tipo_parasitose=0
    - Auxiliary Conduct: [Micoses] Avaliar
        * tipo_micose=0
    - Auxiliary Conduct: [Candidíase] Localização
        * localizacao_candidiase=0
    - Auxiliary Conduct: [Tineas] Avaliar
        * avaliar_tineas=0
- (H) Pediatric Gastroenteritis
    - Auxiliary Conduct: [Desidratação Leve] Idade do Paciente
        * menor_dois_meses=0, maior_dois_meses=0
    - Auxiliary Conduct: Grau de Desidratação
        * grupo_A=0, grupo_b=0, grupo_c=0, nauseas_vomitos=0
- (H) Pediatric Sepsis
    - Auxiliary Conduct: Identificar foco da SEPSE
        * foco_pneumonia=0, foco_pielonefrite=0, foco_meningite=0, foco_outro_foco=0, foco_abdome_agudo-=0, foco_partes_moles=0, foco_neutropenia_febril=0, foco_infeccao_neonatal=0
- (H) Pediatric Traumatic Brain Injury
    - Auxiliary Conduct: [TCE Leve ou Moderado] Idade do Paciente
        * menor_tres_meses=0, entre_tres_meses_dois_anos=0, maior_dois_anos=0
    - Auxiliary Conduct: Avaliar quadro de TCE
        * quadro_tce=0
- (H) Pediatric URTI
    - Auxiliary Conduct: [Otite] Avaliar otite
        * tipo_otite=0
    - Auxiliary Conduct: [Amigdalite] Verificar tipo
        * foco_amigdalite=0
    - Auxiliary Conduct: Avaliar quadro de IVAS
        * quadro_ivas=0
    - Auxiliary Conduct: [Resfriado comum] Avaliar exames
        * S37 (exames alterados)=0, resfriado_alteracao_exames=1
- (H) Pediatric Urticaria
    - Auxiliary Conduct: Verificar Sintomas
        * sintoma_paciente=0
- (H) Postpartum Hemorrhage
    - Auxiliary Conduct: Avaliar Condição
        * condicao_atonia_uterina=0, condicao_resto_placentario=0
- (H) Premature Amniorrexis
    - Auxiliary Conduct: Verificar Idade Gestacional
        * ig-menor-24=0, ig-entre-24-33=0, ig-maior-igual-34=0
    - Auxiliary Conduct: Verificar Via de Parto
        * opcao-parto-cesarea=0, opcao-parto-normal=0
- (H) Preterm Labor
    - Auxiliary Conduct: Avaliar condições
        * condicoes=0
    - Auxiliary Conduct: Reavaliar
        * reavaliacao=0
- (H) Prolonged Gestation

  - Auxiliary Conduct: Avaliar Idade Gestacional e comorbidades
    - idade_gestacional=0
- (H) Pulmonary Embolism
  - Auxiliary Conduct: Avaliar D'DIMERO
    - d_dimero=0
- (H) Sepsis Treatment
  - Auxiliary Conduct: Identificar Foco Infeccioso
    - trat_sepse_pneumo_comunit=0, trat_sepse_pneumo_hosp=0, trat_sepse_cistite=0, trat_sepse_pielonefrite=0, trat_sepse_meningite=0, trat_sepse_partes_moles=0, trat_sepse_abdominal=0, trat_sepse_neutropenia=0, trat_sepse_infeccao_sanguinea=0, trat_sepse_indeterminado=0
- (H) SIRS Treatment
  - Auxiliary Conduct: Identificar foco infeccioso
    - trat_sirs_pneumo_comun=0, trat_sirs_pneumo_hosp=0, trat_sirs_cistite=0, trat_sirs_pielonefrite=0, trat_sirs_meningite=0, trat_sirs_partes_moles=0, trat_sirs_abdominal=0, trat_sirs_neutropenia=0
- (H) Stroke
  - Auxiliary Conduct: Avaliar contraindicações
    - nivel_consciencia=0, p_nivel_consciencia=0, c_nivel_consciencia=0, m_olhar_conjugado=0, campos_visuais=0, paralisia_facial=0, membros_superiores=10, membros_inferiores=10, ataxia_membros=0, sensibilidade=0, linguagem_afasia=5, disartia=0, extincao_desatencao=0, contra_indicacao_trombolise=0
  - Auxiliary Conduct: Hora de ínicio
    - hora_inicio=0
- (H) Systemic Arterial Hypertension
  - Auxiliary Conduct: Apresenta Sintomas Associados?
    - sintomas_associados=0, episodio_has=0
  - Auxiliary Conduct: Classificar Hipertensão
    - emergencia_hipertensiva=0, urgencia_hipertensiva=0, pseudocrise_hipertensiva=0
- (H) URTI
  - Auxiliary Conduct: Avaliar Sintomas Específicos
    - sintomas_influenza=0, sintomas_resfriado=0, sintomas_amigdalite=0, sintomas_rinite=0, rinite=0
  - Auxiliary Conduct: Avaliar a Etiologia
    - rino_etiologia_viral=0, rino_etiologia_bacteriana=0, rino_etiologia_alergica=0
- (H) UTI
  - Auxiliary Conduct: [Pielonefrite] Avaliar Resultados dos Exames
    - resultado_exames=0
  - Auxiliary Conduct: Informar Sexo do paciente
    - sexo_masculino=0, sexo_feminino=0
- (H) UTI in Pregnant Women
  - Auxiliary Conduct: Verificar quantidade de episódios
    - qtd_episodios=0
  - Auxiliary Conduct: Verificar sintomas
    - sintomas=0
  - Auxiliary Conduct: Avaliar resultado Sumário de Urina
    - sumario_urina=0
- (H) Vaginal Discharge
  - Auxiliary Conduct: Verificar tipo do corrimento da gestante
    - tipo_corrimento_gestante=0
  - Auxiliary Conduct: Quantidade de episódios

        - qtd_episodios=0
    - Auxiliary Conduct: Verificar tipo do corrimento da não gestante
        - tipo_corrimento_n_gestante=0
    - Auxiliary Conduct: Verificar gravidez
        - gravidez=0
    - Auxiliary Conduct: Classificar aspectos do corrimento da não gestante
        - corrimento_patologico_n_gestante=0
    - Auxiliary Conduct: Classificar aspectos do corrimento da gestante
        - corrimento_patologico_gestante=0
- (H) Woman Abdominal Pain
    - Auxiliary Conduct: Avaliar condição da mulher
        - gestante_ou_nao=0
    - Auxiliary Conduct: [Gestante] Classificar suspeita conforme dor
        - obstrucao_intestinal=0, dispepsia_drge=0, dor_abdominal_simples=0, suspeita_ITU=0, dores_causa_-nao_obstetrica=0, gestante_complicacoes_obstetricas=0
    - Auxiliary Conduct: [Não Gestante] Classificar suspeita conforme dor
        - ngestante_dor_abdominal_simples=0, ngestante_suspeita_itu=0, ngestante_dores_sangramento=0, ngestante_dip=0, ngestante_gravidez_ectopica=0, ngestante_torcao_ovario=0, ngestante_dores_nao_ginecologica=0
    - Auxiliary Conduct: [Não gestante] [SUD] Avaliar
        - ngestante_sud_avaliar=0

APPENDIX H – NON-DETERMINISM FOUND

- (C) Acne
  - Auxiliary Conduct: Classificar Acne Grau I
    - predominio_comedonico=1, papulo_pustuloso=1
  - Auxiliary Conduct: Classificação do Grau de Severidade
    - grau_i=1, grau_ii=1, grau_iii=1
- (C) Acute Otitis Media
  - Auxiliary Conduct: Escolher tratamento: Adulto
    - opcao_tratamento_adulto=0, UM=0, DOIS=0
  - Auxiliary Conduct: Escolher tratamento: Pediátrico
    - opcao_tratamento_pediatrico=0, UM=0, DOIS=0
- (C) African Line Doubletherapy
  - Auxiliary Conduct: Verificar Medicação
    - medicacao_linha_duplo_afro=0, UM=0, DOIS=0
- (C) African Line Monotherapy
  - Auxiliary Conduct: Selecionar Medicação
    - selecionar_medicacao_mono_linha_afro=0, UM=0, DOIS=0
- (C) African Line Tetratherapy
  - Auxiliary Conduct: Verificação de Medicação
    - medicacao_linha_tetra_afro=0, DOIS=0, UM=0
- (C) African Line Tripletherapy
  - Auxiliary Conduct: Verificação de Medicação
    - medicacao_linha_triplo_afro=0, UM=0, DOIS=0
- (C) Allergic Rhinitis
  - Auxiliary Conduct: [Rinite Persistente] Idade
    - rin_pers_6_a_11_meses=1, rin_pers_12_meses_a_2_anos=0, rin_pers_2_a_5_anos=1, rin_pers_6_a_11_anos=1, rin_pers_12_anos_a_adulto=1
  - Auxiliary Conduct: [Rinite Persisntente] Peso
    - rin_pers_2_a_5_anos=1, rin_pers_peso=0, 2=0, 1=0, rin_pers_6_a_11_anos=0, rin_pers_12_anos_a_adulto=1
  - Auxiliary Conduct: Exame Físico
    - obstrucao_unilateral_polipo_ou_tumor=1, obstrucao_unilateral_desvio_septo=0, obstrucao_unilateral_corpo_estranho=0, obstrucao_unilateral_polipo_ou_tumor=1, 1=2
  - Auxiliary Conduct: Classificação da Rinite
    - classificacao_rinite=0, 1=0, 3=1, 4=1, 2=0
  - Auxiliary Conduct: [Rinite Intermitente] Idade
    - rin_interm_6_a_11_meses=1, rin_interm_11_meses_a_2_anos=0, rin_interm_2_a_5_anos=1, rin_interm_6_a_11_anos=1, rin_interm_12_anos_adulto=1
  - Auxiliary Conduct: [Rinite Leve, Persistente ou Grave] Peso
    - rin_leve_2_a_5_anos=1, rinite_leve_peso=0, 1=0, 2=0, rin_leve_6_a_11_anos=0, rin_leve_acima_de_12_anos=1
  - Auxiliary Conduct: [Rinite Intermitente] Peso
    - rin_interm_2_a_5_anos=1, rin_interm_peso=0, 2=0, 1=0, rin_interm_6_a_11_anos=0, rin_interm_12_anos_adulto=1
  - Auxiliary Conduct: [Rinite Leve, Moderada ou Grave] Idade
    - rin_leve_6_a_11_meses=1, rin_leve_12_meses_2_anos=0, rin_leve_2_a_5_anos=1, rin_leve_6_a_11_-

anos=1, rin_leve_acima_de_12_anos=1

- (C) Backache
  - Auxiliary Conduct: Classificação da Intensidade da Dor
    - classificacao_leve_moderada=1, classificacao_dor_severa=1, classificacao_dor_aguda_com_espasmos=1
- (C) Cardiac Insufficiency
  - Auxiliary Conduct: Comorbidades (B ou C)
    - comorbidades_encaminhamento_cardio=1, comorbidades_reclassificação=1
  - Auxiliary Conduct: Classificar Estágio e Classe da Insuficiência Cardíaca
    - estagio_b=1, classe_1=1, classe_2=1, estagio_c=1, classe_3=0, classe_4=0, estagio_a=1
  - Auxiliary Conduct: Condutas em Comum
    - ps_maior_140_ou_pd_maior_90=1, dislipidemia=0, diabetes=1
- (C) Diabetes Mellitus
  - Auxiliary Conduct: Escolher Monoterapia
    - monoterapia_opcao1=1, monoterapia_opcao2=1
  - Auxiliary Conduct: Escolher Duploterapia
    - duploterapia_opcao1=1, duploterapia_opcao2=1
  - Auxiliary Conduct: Nível de HbA1c
    - nivel_hba1c_menor_7_5=1, nivel_hba1c_entre_7_e_9=1, nivel_hba1c_maior_9=1
- (C) Diabetes Treatment
  - Auxiliary Conduct: Escolher Monoterapia
    - monoterapia_opcao1=1, monoterapia_opcao2=1
  - Auxiliary Conduct: Escolher Duploterapia
    - duploterapia_opcao1=1, duploterapia_opcao2=1
  - Auxiliary Conduct: Nível de HbA1c
    - nivel_hba1c_menor_7_5=1, nivel_hba1c_entre_7_e_9=1, nivel_hba1c_maior_9=1
- (C) Dyslipidemia
  - Auxiliary Conduct: Idade/Sexo
    - paciente_sexo_masculino=1, paciente_idade=1, 40=1, paciente_sexo_feminino=1, 50=0
- (C) FP Diarrhea
  - Auxiliary Conduct: Reavaliar Sinais e Sintomas
    - sinais_sintomas_paciente=0, UM=0, DOIS=1, TRES=0
- (C) FP Vertigo
  - Auxiliary Conduct: Classificar Vertigem
    - vertigem_intensa=1, nistagmo_horizontal=1, nistagmo_fatigavel=1, tinitus_ou_hipocacusia=1, 2=0, vertigem_branda=1, nistagmo_ataxico=1, nistagmo_nao_fatigavel=0, outros_sintomas_neurologicos=1
  - Auxiliary Conduct: Classificar Vertigem Posicional
    - vertigem_posicional_meniere=1, vertigem_posicional_vppb=1
- (C) Headache
  - Auxiliary Conduct: Avaliar se houve melhora
    - resposta_satisfatoria_tratamento=1, piora_sintomas=1, acometimento_neurologico=1
  - Auxiliary Conduct: Realizar Avaliação para Cefaléia Primária
    - paciente_enxaqueca=1, paciente_cefaleia_tensional=1, paciente_outro_tipo_cefaleia=1
  - Auxiliary Conduct: Prescrever tratamento
    - tratamento_crise_enxaqueca=1, tratamento_cefaleia_tensional_cronica=1, tratamento_outros_tipos_cefaleia=1
- (C) Hyperkalemia
  - Auxiliary Conduct: Avaliar exame de Potássio

        * exame_potassio_serico=1, 6=0, 5, 5=1, paciente_sintomas=0
- (C) Hypothyroidism
    - Auxiliary Conduct: Critérios de encaminhamento
        * encaminhamento_menor_18_anos=0, encaminhamento_tratamento_sem_resposta=1, encaminhamento_bocio_ou_nodulo=1, encaminhamento_hipotireoidismo_secundario=1, encaminhamento_hipertireoidismo=1, encaminhamento_gestante=1, encaminhamento_menor_18_anos=0, encaminhamento_tratamento_sem_resposta=1, encaminhamento_gestante=1, encaminhamento_bocio_ou_nodulo=1, encaminhamento_hipotireoidismo_secundario=1, encaminhamento_hipertireoidismo=1, 1=6
    - Auxiliary Conduct: Avaliar TSH
        * tsh=0, 0, 27=1, 4, 2=1, 10=0
- (C) Joint Pain
    - Auxiliary Conduct: [Monoarticular Crônica] Suspeita de diagnóstico
        * monoarticular_artrite_reativa=1, monoarticular_psoriase=1
    - Auxiliary Conduct: [Poliarticular Aguda] Suspeita de Diagnóstico
        * gonococcemia_poliarticular_aguda=1, artrite_reativa_poliarticular_aguda=1
    - Auxiliary Conduct: [Inflamatória] Monoarticular ou Poliarticular?
        * mono_ou_poliarticular=0, 1=0, 2=0
    - Auxiliary Conduct: [Poliarticular Crônica] Suspeita de Diagnóstico
        * poliarticular_cronica_artrite_lupica=1, poliarticular_cronica_artrite_reumatoide=1
    - Auxiliary Conduct: [Monoarticular] Aguda ou Crônica?
        * monoarticular_dor_aguda_ou_cronica=0, 2=0, 1=0
    - Auxiliary Conduct: [Poliarticular] Aguda ou Crônica?
        * dor_poliarticular=0, 2=0, 1=1, 3=0
    - Auxiliary Conduct: [Monoarticular Aguda] Suspeita de diagnóstico
        * monoarticular_aguda_gota=1, monoarticular_aguda_artrite_septica=1
    - Auxiliary Conduct: [Dor Inflamatória da Coluna] Suspeita de Diagnóstico
        * dor_lombar_baixa=1, espongilite_anquilosante=1
- (C) Kidney Transplant
    - Auxiliary Conduct: Verificar sexo do paciente
        * sexo_paciente=0, 1=0, 2=0
- (C) Low Risk Dyslipidemia Treatment
    - Auxiliary Conduct: Selecionar Terapia
        * terapia_medicação=1, terapia_mudanca_estilo_vida=1, terapia_medicacal_avulsa=1
- (C) Parasitosis
    - Auxiliary Conduct: Sinais e Sintomas
        * paras_sinais_sintomas=0, UM=0, TRES=1, DOIS=0, OITO=1, QUATRO=0, SETE=1, CINCO=0, SEIS=0, NOVE=0
    - Auxiliary Conduct: Condições de encaminhamento (Urgência)
        * condicoes_encaminhamento=2, UM=0, DOIS=3
- (C) Pharyngitis
    - Auxiliary Conduct: Definir encaminhamentos
        * imc_irregular=1, 7_ou_mais_episodios=1, suspeita_difteria=1
- (C) Sinusitis
    - Auxiliary Conduct: Diagnóstico Diferencial
        * corpos_estranhos_nasais=1, atresia_de_coana_unilateral=1, rinite_alergica=1, adenoidite=1
    - Auxiliary Conduct: [Sinusite] Avaliação do Quadro
        * sinusite_Aguda=1, sinusite_complicada=0, sinusite_cronica=1, sinusite_recorrente=1, outras_doencas=1

  - Auxiliary Conduct: [Sinusite Recorrente ou Crônica] Diagnósticos Diferenciais
    - diagnosticos_diferenciais_rinite_alerGica=1, diagnosticos_diferenciais_hipertrofia_adenoide=0, diagnosticos_diferenciais_doencas_sistemicas=1, diagnosticos_diferenciais_refluxo=1, diagnosticos_diferenciais_variacoes_anatomicas_cavidade_nasal=1
- (C) UTI
  - Auxiliary Conduct: [Retorno] Avaliar paciente
    - avaliar_paciente=0, 1=0, 2=1, 3=0
  - Auxiliary Conduct: Avaliar idade
    - faixa_etaria=0, 1=0, 2=0, 3=1, 4=0
- (C) Vulvovaginitis
  - Auxiliary Conduct: Consulta de Retorno
    - vulvovaginite_recorrente=1, resolucao_do_quadro_clinico=1, paciente_hiv_positiva=1
  - Auxiliary Conduct: Verificar Sinais e Sintomas
    - candidiase=1, vaginose_bacteriana=1, tricomoniase=1
- (H) Abdominal Pain
  - Auxiliary Conduct: Classificar suspeita conforme dor
    - obstucao_intestinal=1, pancreatite_aguda=1, nefrolitíase=1, apendicite_aguda=1, colecistite_aguda=1, diverticulite_aguda=1, doenca_inflamatoria_pelvica=1, ulcera_gastrica=1, dor_apos_trauma=1, torcao_do_ovario=1, colangite_aguda=0, aneurisma_aorta_abdominal=0, dispepsia_drge=0, gravidez_ectopica=1, infarto_mesenterico=0, hernia_abdominal=0, diagnostico_inconclusivo=1, dor_abdominal_simples=1, mais_de_duas_ocorrencias=1
- (H) Asthma
  - Auxiliary Conduct: Avaliar Intensidade da Crise
    - crise_leve=1, crise_moderada_ou_grave=1
- (H) Chest Pain
  - Auxiliary Conduct: Caracterização da Dor Torácica
    - dor_tipo_A=1, dor_tipo_B=1, dor_tipo_C=1, dor_tipo_D=1
  - Auxiliary Conduct: Procurar outras causas
    - outras_causas_pneumonia=1, outras_causas_tep_pneumotorax=1, outras_causas_disseccao=1, outras_causas_pericardite=0, outras_causas_drge_espasmo_esofagiano=1, outras_cauasas_dor_musculo_esqueletica=1, outras_causas_dor_psicogenica=1
- (H) Deep Vein Thrombosis
  - Auxiliary Conduct: Avaliar condições do paciente
    - TVP_maciço=0, embolia_pulmonar=0, alto_risco_de_sangramento=0, comorbidades=0, gravidez=1
  - Auxiliary Conduct: Escore de Wells
    - tep=1, escore_wells=-2, 0=0
- (H) Dermatological Disorders
  - Auxiliary Conduct: [Afecções das Unhas] Sintomas
    - unha_encravada_sem_infeccao=1, onicomicose=1, unha_encravada_com_infeccao=1
  - Auxiliary Conduct: Avaliação do Quadro
    - celulite=1, urticaria=1, impetigo=1, pe_diabetico=1, escabiose=0, queimaduras=1, afeccoes_das_unhas=1, cispo_pilonidal=1, abcesso_cutaneo=1
  - Auxiliary Conduct: Definir Grau da Queimadura
    - queimadura_grau_i=1, queimadura_grau_ii=1, queimadura_grau_iii=1
- (H) Diarrhea
  - Auxiliary Conduct: [Grupo B] Reavaliar paciente
    - semsinais_semdesidratacao=1, comsinais_semdesidratacao=0, semsinais_comdesidratacao=0, comsinais-

_comdesidratacao=1

  - Auxiliary Conduct: [Grupo B com Diarreia Cronica] Avaliar exames e melhora
    - semalteracoes_commelhora=1, semalteracoes_semmelhora=1, comalteracoes=1
- (H) Earache
  - Treatment: Medicação para dor
    - acometimento_pavilhao_auricular=1, otite_media=1, otite_externa=1
- (H) Exposed Fracture
  - Auxiliary Conduct: Verificar Grau da Fratura
    - frat-grau12=1, frat-grau34=1
- (H) Fever Without Location Signs
  - Auxiliary Conduct: Avaliar Idade
    - idade_menor_28_ddv=1, idade_1_a_3_meses=1, idade_maior_3_meses=1
- (H) Headache
  - Auxiliary Conduct: [Cefaleia Primaria] Classificar Cefaleia
    - cefaleia_primaria_tensional=1, cefaleia_primaira_em_salvas=0, cefaleia_primaria_enxaqueca=0, retorno=1
- (H) Heart Block
  - Auxiliary Conduct: Confirmar infecção
    - confirmar_infeccao_apos_exames=1, confirmar_infeccao=2
- (H) Herpes Virus Infection
  - Auxiliary Conduct: [Varicela] Avaliar Sintomas
    - varicela_infeccao_secundaria=1, varicela_imunossupressao_e_outros_sintomas=1
  - Auxiliary Conduct: Avaliação do Quadro
    - herpes_genital=1, herpes_labial=0, herpes_zoster=0, varicela=1
- (H) High Digestive Bleeding
  - Auxiliary Conduct: Marcador de Risco
    - glasgow_ureia=0, glasgow_hemoglobina_homem=1, glasgow_pas=0, glasgow_pulso=0, glasgow_melena=0, glasgow_sincope=0, glasgow_doenca_hepatica=0, glasgow_insuficiencia_cardiaca=0, zero=1, glasgow_hemoglobina_mulher=0
- (H) Hypertensive Syndrome
  - Auxiliary Conduct: [IG >= 20] Avaliar Quadro
    - maior20_pressao=1, maior20_sinais_cronicos=2, maior20_exames_laboratoriais=0, maior20_usg=1
- (H) Low Back Pain
  - Auxiliary Conduct: Analisar resultados exames
    - suspeita_calculo=1, calculo_presente=1
- (H) Musculoskeletal Pain
  - Auxiliary Conduct: Monoartrite Aguda
    - artrite_septica=1, artrite_gotosa=1, artrite_pos_traumatica=1
  - Auxiliary Conduct: Classificar Dor
    - monoartrite=1, oligo_ou_poliartrite=1, artrite_cronica=1, artralgia_osteoartrose=0, trauma_musculoesqueletico=1, tendinite_tendossino_epicondi_bucite_dort=1, trauma_com_fratura_ou_limitacao=1
- (H) Nausea and Vomiting
  - Auxiliary Conduct: Sintomas do Paciente
    - emese_gravidica=1, cefaleia_nauseas_vomitos=1, dor_abdominal_nauseas_vomitos=1, dor_toracico_nauseas_vomitos=0, diarreia_nauseas_vomitos=1, dor_lombar_nauseas_vomitos=1, tontura_nauseas_vomitos=0, tratamento_quimioterapico_nauseas_vomitos=1, ingestao_alcool_nauseas_vomitos=1, sem_causa_aparente_nauseas_vomitos=1

- (H) Obstetric Nausea and Vomiting
  - Auxiliary Conduct: Sintomas do Paciente
    - emese_gravidica=1, cefaleia_nauseas_vomitos=1, dor_abdominal_nauseas_vomitos=1, dor_toracico_-nauseas_vomitos=0, diarreia_nauseas_vomitos=1, dor_lombar_nauseas_vomitos=1, tontura_nauseas_-vomitos=0, tratamento_quimioterapico_nauseas_vomitos=1, ingestao_alcool_nauseas_vomitos=1, sem_-causa_aparente_nauseas_vomitos=1
- (H) Pediatric Dermatological Disorders
  - Auxiliary Conduct: [Afecções das Unhas] Sintomas
    - unha_encravada_sem_infeccao=1, onicomicose=1, unha_encravada_com_infeccao=1
  - Auxiliary Conduct: Avaliação do Quadro
    - celulite=1, urticaria=1, impetigo=1, queimaduras=0, afeccoes_das_unhas=1, cispo_pilonidal=1, abcesso-_cutaneo=0, dermatites=1, micoses=1, parasitoses=1
  - Auxiliary Conduct: Definir Grau da Queimadura
    - queimadura_grau_i=1, queimadura_grau_ii=1, queimadura_grau_iii=1
- (H) Pediatric Gastroenteritis
  - Auxiliary Conduct: [Desidratação Leve] Idade do Paciente
    - menor_dois_meses=1, maior_dois_meses=1
  - Auxiliary Conduct: Grau de Desidratação
    - grupo_A=1, grupo_b=0, grupo_c=0, nauseas_vomitos=1
- (H) Pediatric Sepsis
  - Auxiliary Conduct: Identificar foco da SEPSE
    - foco_pneumonia=0, foco_pielonefrite=0, foco_meningite=0, foco_outro_foco=0, foco_abdome_agudo-=1, foco_partes_moles=1, foco_neutropenia_febril=1, foco_infeccao_neonatal=1
- (H) Pediatric Traumatic Brain Injury
  - Auxiliary Conduct: [TCE Leve ou Moderado] Idade do Paciente
    - menor_tres_meses=1, entre_tres_meses_dois_anos=1, maior_dois_anos=1
- (H) Pediatric URTI
  - Auxiliary Conduct: [Resfriado comum] Avaliar exames
    - S37 (exames alterados)=1, resfriado_alteracao_exames=0
- (H) Postpartum Hemorrhage
  - Auxiliary Conduct: Avaliar Condição
    - condicao_atonia_uterina=1, condicao_resto_placentario=1
- (H) Premature Amniorrexis
  - Auxiliary Conduct: Verificar Idade Gestacional
    - ig-menor-24=1, ig-entre-24-33=1, ig-maior-igual-34=1
  - Auxiliary Conduct: Verificar Via de Parto
    - opcao-parto-cesarea=1, opcao-parto-normal=1
- (H) Sepsis Treatment
  - Auxiliary Conduct: Identificar Foco Infeccioso
    - trat_sepse_pneumo_comunit=1, trat_sepse_pneumo_hosp=1, trat_sepse_cistite=1, trat_sepse_pielonefrite=0, trat_sepse_meningite=1, trat_sepse_partes_moles=1, trat_sepse_abdominal=0, trat_sepse_neutropenia=1, trat_sepse_infeccao_sanguinea=1, trat_sepse_indeterminado=1
- (H) SIRS Treatment
  - Auxiliary Conduct: Identificar foco infeccioso
    - trat_sirs_pneumo_comun=1, trat_sirs_pneumo_hosp=0, trat_sirs_cistite=1, trat_sirs_pielonefrite=0, trat-_sirs_meningite=1, trat_sirs_partes_moles=1, trat_sirs_abdominal=1, trat_sirs_neutropenia=1
- (H) Systemic Arterial Hypertension

  - Auxiliary Conduct: Classificar Hipertensão
    - emergencia_hipertensiva=1, urgencia_hipertensiva=1, pseudocrise_hipertensiva=1
- (H) URTI
  - Auxiliary Conduct: Avaliar Sintomas Específicos
    - sintomas_influenza=1, sintomas_resfriado=0, sintomas_amigdalite=0, sintomas_rinite=0, rinite=1
  - Auxiliary Conduct: Avaliar a Etiologia
    - rino_etiologia_viral=1, rino_etiologia_bacteriana=1, rino_etiologia_alergica=1
- (H) UTI
  - Auxiliary Conduct: Informar Sexo do paciente
    - sexo_masculino=1, sexo_feminino=1
- (H) Woman Abdominal Pain
  - Auxiliary Conduct: [Gestante] Classificar suspeita conforme dor
    - obstrucao_intestinal=1, dispepsia_drge=0, dor_abdominal_simples=1, suspeita_ITU=0, dores_causa_nao_obstetrica=1, gestante_complicacoes_obstetricas=1
  - Auxiliary Conduct: [Não Gestante] Classificar suspeita conforme dor
    - ngestante_dor_abdominal_simples=1, ngestante_suspeita_itu=0, ngestante_dores_sangramento=1, ngestante_dip=0, ngestante_gravidez_ectopica=1, ngestante_torcao_ovario=1, ngestante_dores_nao_ginecologica=1

APPENDIX I – INACCESSIBLE STEPS FOUND

- (C) Allergic Rhinitis
  - Prescription: [Mild, Moderate or Severe Rhinitis] tratamento
- (C) BAR BBC Betablocker
  - Referral: [Encaminhamento] BAR Tetrotherapy
- (H) Abdominal Pain
  - Treatment: Exam Standard (for step copy)
- (H) Asthma
  - Prescription: [Moderate or Severe Crisis] Receita
- (H) Hypertensive Syndrome
  - Information: [Puerperium] Intern
  - Treatment: [Puerperium] Request Examinations
  - Auxiliary Conduct: [Puerperium] Evaluate Examinations
  - Information: [Puerperium] MAP + PN
- (H) Premature Amniorrexis
  - Treatment: GBS Prophylaxis - Normal Birth
  - Treatment: GBS Prophylaxis - Cesarean Section
  - Auxiliary Conduct: Verify Childbirth Pathway
- (H) Preterm Labor
  - Information: Reevaluate Again
  - Auxiliary Conduct: Reevaluate 2nd
- (H) UTI in Pregnant Women
  - Information: Reevaluate Patient
  - Auxiliary Conduct: Check Improvement
  - Prescription: Receita 03