GOAL REALIZATION FRAMEWORK TO OPTIMIZE MEDICAL WORKFLOW
MODEL AND GENERATE PLAN LIBRARIES

By

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ABSTRACT OF THE THESIS

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The number of patient deaths due to medical errors has increased in the past decade due to either human errors or errors in computer-aided decision support systems. These systems are often modeled using an expert medical algorithm and the plans of action based on the experts' theoretical knowledge and medical experience. But these approaches are prone to errors as the algorithm and the plans might have errors of omission and commission. Hence, there is a need to validate the expert algorithm and determine the correct plans which motivated this study. I have developed the goal realization framework for a medical goal named Establish IV Access (IV Goal) that optimized the IV realization algorithm based on the ground truth, i.e., medical process logs. I have built another framework that could detect the ground truth from the dataset where the IV goal was truly met to determine the medical algorithm’s accuracy, i.e., realization framework's accuracy. After multiple experiments, analysis, conclusions, and revisions of the algorithm, the expert model (algorithm) was optimized, and thus the goal realization framework achieved an accuracy of 100%. Other statistical analyses like age distribution of patients getting single v/s multiple IV attempts and traces following different branches (paths of the workflow) helped experts understand the standard medical
procedure followed in the real-world for performing the IV goal. Using the optimized algorithm, we had determined eight concise and granular plan libraries that could be sent out as part of recommendations in the trauma resuscitation process while performing the IV goal. The optimized algorithm (expert workflow model) is often challenging to interpret. Hence, workflow discovery algorithms or process mining tools have been developed that generate interpretable workflows or process maps. The data used for workflows is often synthetic or formed manually by the experts and motivated to build a third framework that could generate the dataset for a medical goal using the ground truth, i.e., medical process logs. The workflow developed using ideas from previous work and workflow discovery algorithms like PIMA is compared with the optimized expert algorithm to determine its fitness based on paths followed by traces and the statistical results generated from the goal realization framework.
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1. Introduction

There has been a significant rise in the deaths caused by errors during medical practice: nearly 251000 deaths happen annually in the United States (US)\textsuperscript{[3]}. Medical errors\textsuperscript{[8]}, especially during trauma resuscitations, can be due to the following reasons: (1) The proper plan of action or the mandatory action plans are not performed while performing the medical procedure. (2) Human errors due to which required outcome is not met. (3) Performing medical practice in a way that deviates from an actual procedure. (4) The act of omission or commission while performing or planning a medical process. Healthcare organizations are constantly trying to adopt “a culture of safety” to improve the process by having a retrospective view of medical errors among the team\textsuperscript{[8]}. Frameworks like Computer-Aided decision support systems have been developed, and innovations are made every year to assist the frontline workers during the trauma resuscitation process and perform life-saving operations.

While such systems are beneficial, many factors must be considered to ensure utmost accuracy. Realizing the medical process (medical goal) that is being performed and recommending the plans for the same during the trauma resuscitation processes are the critical tasks that the system does. Expert-based medical workflow models that the medical experts derive are used during the realization and recommendation steps to assist healthcare workers with resuscitation activities to be followed during the trauma resuscitation process. These models and plan libraries are derived based on their theoretical knowledge or practical experience.
2. Problem Statement

Workflow models (expert models) and the plan libraries used to model the recommendation systems are derived after multiple iterations and revisions by medical experts based on their theoretical knowledge and practical experience. Designing a recommendation system in such a way is often a bad practice. There is a high risk that critical plans of actions and workflows would be missed due to a lack of practical experience or lack of deep medical knowledge. As a result, the system will not send correct recommendations during the trauma resuscitations, thus increasing death chances if the patient is not treated correctly. It is sometimes difficult to comprehend the models that experts derive because of the complex nature (spaghetti model). Workflow discovery algorithms and tools like DISCO have been developed recently to create interpretable process maps, but the dataset used is often synthetic or created manually by experts and is prone to errors.

It is essential to repair/optimize the expert model and generate plan libraries using the medical process logs rather than theoretical knowledge. Because the medical process logs are the ground truth, i.e., consist of the processes and resuscitation activities followed in real scenarios. Thus, the resultant model and plans derived from data would be far more accurate. Therefore, recommendation systems would send correct plans during resuscitations that can save the lives of the patients. Also, the need for generating simplified workflows (linear model) based on ground truth data rather than synthetic data is needed for better interpretation of real-life medical processes.

This work aims to build a framework that could find the deviations and errors in the expert model and help optimize/repair the same based on the ground truth (medical process
logs). The optimized expert model could later generate plan libraries that the system will use to recommend the right plans to follow during the resuscitation process. Moreover, the statistical results that the framework generates could be used to analyze the common practice of pursuing a medical goal and also gain other valuable insights. This work also focuses on developing another framework that produces a dataset from the ground truth used by popular automatic workflow discovery algorithms and tools to discover interpretable workflow models.

3. Hypothesis

Optimizing/Repairing an expert model using the ground truth data can determine accurate plan libraries that could be used to design recommendation systems. Also, interpreting workflow models created based on ground truth data helps better understand the medical processes.

This work aims to optimize/repair an expert model by finding deviations and errors in the model using a data-driven framework based on the ground truth and creating plan libraries. The accuracy of the model and framework is determined based on the ground truth. Hence, multiple experiments have been performed to improve the framework accuracy incrementally until it is 100% accurate. With every experiment performed, new deviations and errors are discovered in the model and the ground truth data. Statistical results discussed in several experiments can also help experts determine the medical process followed in practice.

Another aim of this work is to create interpretable workflow models and understand the real-world medical process using ground truth data rather than the traditional practice
of using synthetic data. Hence, a framework has been developed to create a dataset from ground truth that workflow discovery algorithms and tools can understand to generate workflow models that align with real-world processes.

4. Description of the dataset

4.1. Activity Trace Dataset

These are the medical process logs that the medical team code for each case or patient on whom the trauma resuscitation process has been performed. These traces consist of different medical resuscitation activities performed by the frontline healthcare providers during the process. The teams’ resuscitation activities performed directly relate to the corresponding goal. For example, for establishing intravascular access on the patient (IV Access), the team performs and follows a specific activity sequence. Likewise, we would have resuscitation activities related to other medical goals like Intubation, Ventilation, etc., all performed in parallel.

These Activity Trace Dataset are the ground truth, i.e., the actual real-life processes performed during resuscitation. There are 271 traces (earlier 265 traces) with different medical goals performed in each of them, thus constituting various activities for those medical goals. Below are some of the required related fields of the traces used in this work and Figure 1. Medical Process Log Excerpt from Activity Trace Dataset highlights those relevant fields:

- Onset_time and Offset_Time – These are the start and end times of an activity performed during resuscitation.
- Code – Activity name denoting the resuscitation activity performed.
- **C_S** – Attribute associated with activity denoting the status of resuscitation activity (Successful/Complete or Unsuccessful)

Figure 1. Medical Process Log Excerpt from Activity Trace Dataset [Source: Medical Process Logs provided by CNMC experts]

Figure 2 represents the histogram of the different resuscitation activities’ frequency across those 271 traces, showing how diverse and complex the dataset is. Medical experts can also look at this histogram and express their views regarding the essential activities that are frequently performed in Activity Trace Dataset and the goal associated with those activities.
4.2. Resuscitation Activity Lists based on Medical Goal

As previously discussed in Activity Trace Dataset, a single trace might have multiple medical goals performed in parallel. Thus, there would be different resuscitation activities related to those goals performed in parallel for each trace. However, to generate the plan libraries for each of the medical goals and their respective workflow models using process mining techniques, we need to have a list of resuscitation activities performed for each goal and work on a single medical goal at a time.

Thus, the medical experts provided resuscitation activity lists based on medical goals. The framework could extract activities related to a particular medical goal across all
Activity Traces, discover and analyze workflow models, find deviations and errors in the expert model, and get other vital insights. Previously, there was no framework or tool developed that can be used to extract resuscitation activities related to medical goals and perform experiments on those sequences only, which is ground truth. The medical team used to create a dataset manually by referring videos or these traces and generate the series of resuscitation activities performed in each trace for a medical goal. However, I had developed a framework that extracts sequences of resuscitation activities from Activity Trace Dataset for a particular goal based on the goal list that experts provide and find deviations and errors in medical workflows discussed in later section of this thesis document.

Table 1. shows an example of resuscitation activities performed for some of the medical goals like Establish IV Access, Maintain Blood Pressure, Control Hemorrhage, etc. The number present behind the resuscitation activity denotes the frequency of the activity performed across all the 271 Activity Trace Dataset.

<table>
<thead>
<tr>
<th>Establish IV Access</th>
<th>Maintain Blood Pressure</th>
<th>Control Hemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV Placement (264)</td>
<td>MBP (298)</td>
<td>FAST (5)</td>
</tr>
<tr>
<td>IV Placement Confirmation (101)</td>
<td>ABP (683)</td>
<td>Doppler Exam (8)</td>
</tr>
<tr>
<td>Drill to Skin (1)</td>
<td>ABP Cuff Placement (311)</td>
<td>Pressure dressing (0)</td>
</tr>
<tr>
<td>Local anesthesia (2)</td>
<td>IV bolus connected (49)</td>
<td>Tourniquet (0)</td>
</tr>
<tr>
<td>Skin incision (1)</td>
<td>IV bolus disconnected (21)</td>
<td>Suture ligation (0)</td>
</tr>
<tr>
<td>Anatomy Ided (1)</td>
<td>IV Bolus Given (66)</td>
<td>Hemorrhage Ided (0)</td>
</tr>
<tr>
<td>Activity</td>
<td>Frequency</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>IV bolus connected</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Response assessed</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Manual pressure</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>IV bolus disconnected</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>IV Bolus Given</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Blood Drawn</td>
<td>456</td>
<td></td>
</tr>
<tr>
<td>Pain Medication</td>
<td>163</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Resuscitation Activity Lists based on Medical Goals. [Source: List is provided by CNMC experts]

Since the Activity Trace Dataset consists of a significantly less number of Hemorrhage goal performed in it, we see low frequencies of resuscitation activities performed for “Control Hemorrhage.” Whereas establishing IV is performed in nearly all the traces, the frequencies of activities for Establishing IV Access goal are very high.

5. Types of Process Mining Techniques used

Process Mining is the technique to create workflow models using the process logs (ground truth) and interpret the real-life processes followed in the real world. According to “Process Mining Manifesto” [1], there are 3 types of process mining techniques [1], which we have used in this work:

1. Conformance Checking: This technique will help us determine the deviations/errors in the expert model using each trace of the Activity Trace Dataset. Activity Sequences of the IV goal from each trace will be passed through the expert
model (goal realization framework) for a conformance check to determine deviations/errors.

2. Enhancement: Using this technique, we will optimize/repair the expert model and perform the conformance check again until the model is not enhanced.

3. Discovery: This technique primarily creates workflow models that can be used to interpret the medical processes.

Figure 3. represents the process mining types according to “Process Mining Manifesto” \cite{1}.

![Figure 3. Types of Process Mining Techniques \cite{1} (Source: Extracted from “Process Mining Manifesto” \cite{1})]

The first part of the thesis focuses on optimizing/repairing the expert model using conformance checking and enhancement process mining types \cite{1}. The second part focuses on generating interpretable workflow models using the discovery process mining type \cite{1} that the process mining tools and algorithms provide.

6.1. Introduction

Clinical teams follow a specific workflow while performing a medical procedure during trauma resuscitation to meet a medical goal. For example, suppose the team wants to Establish an IV Access (also called IV Goal). In that case, the general steps to consider are a) tourniquet placement, b) venipuncture (sticking the needle in), c) confirmation attempt (anything going into or out of the line - blood draw, flush, meds, bolus, etc.). If the IV is not placed appropriately, these confirmation attempts might fail.

Experts try to create the best possible versions of these models based on their theoretical knowledge and refer to those models during the trauma resuscitation process. The models are also called Goal Realization Algorithms. The computer-aided systems designed using those expert-based models would be very erroneous if the model is not 100% accurate. Hence, concerns would be raised regarding the accuracy of the recommendations and the system's plans if the system does not display the correct suggestions and plans to the frontline workers.

In the real-life trauma resuscitations processes, the workflow and the sequence of activities followed are very different. Thus, there would always be a gap and a problem if the expert-based model is not derived based on the real-life medical process data. These gaps could be deviations from medical procedures due to errors of omission and commission [8] that could help us determine new ways to perform and meet a goal and modify the existing ways of pursuing a goal. Moreover, using medical process data, we could also derive linear models that are easy to understand using workflow discovery
algorithms \cite{algorithms} or use tools like DISCO (https://fluxicon.com/disco/) to discover the process maps automatically. Apart from errors in the expert model, there could also be errors in the process data, i.e., Activity Trace Dataset, which could lead to an incorrect generation of workflow models using tools and workflow discovery algorithms.

In this section, we will discuss how the framework developed helped repair/optimize the expert-based model, generate the plan libraries, fix the coding errors in Activity Trace Dataset, and lastly, derive some valuable insights from the statistical results. Our only focus in this study is on a medical goal named “Establish IV Access,” also described as an IV Goal throughout the thesis document.

6.2. Expert Workflow Model – IV Goal

Initially, the experts had formed a hand-drawn IV workflow model using their theoretical knowledge and practical experience. Figure 4. shows the initial version of the expert model with very few branches/paths that the medical team theoretically follows to perform IV Goal.
The problem with the model shown in Figure 4 is that the activity performed at each node of the flowchart does not match the resuscitation activity names present in the
Activity Trace Dataset. Hence, experts had to develop the new version of the expert model, also called the IV Goal Realization Algorithm, which could conform with the activity names present in Activity Trace Dataset. Figure 5. shows the original version of the IV Realization Algorithm that experts had formed based on their theoretical knowledge containing resuscitation activity names that correspond with the activity names found in the Activity Trace Dataset (ground truth).
Figure 5. Version 2 of the IV Realization Algorithm [Source: Workflow is provided by CNMC experts]
6.3. Development of Goal Realization Framework

There was no framework developed previously in the project that validates the expert-based model's accuracy as it was created entirely based on the experts' theoretical knowledge. I developed a goal realization framework to find deviations and errors in the expert model and analyze them. This framework extracts resuscitation activity sequences related to the IV goal from each Activity Trace. It checks the conformance with the expert model as Activity Trace Dataset are the ground truth, i.e., medical processes followed during medical practice. Traces that do not adhere to the expert model entirely or follow the expert model partially can be investigated further.

The investigation of non-conforming traces further helps find deviations and errors that can be fixed to optimize/repair the expert model, i.e., the IV Goal Realization Algorithm. The consequences of it are fairly positive as upon multiple revisions and conformance check of Activity Trace Dataset with realization algorithm; it helps improve the accuracy of the model and find new avenues of how the goal could be performed (the plan libraries).

Apart from improving the accuracy, this framework has also helped to improve the quality of coded Activity Trace Dataset by finding the errors in the coding that might be caused due the below reasons:

- Errors of coding during video review
- Omitted resuscitation activities (because of the trauma team’s error of omission
- Out of order resuscitation activities (because of the trauma team’s error of scheduling)
- Redundant resuscitation activities (because of the trauma team’s error of commission)
Lastly, the framework generates the statistics regarding the workflow and paths followed by Activity Trace Dataset to pursue the goal. Statistics like frequency of paths/branches, followed in the expert model and the number of traces that follow these paths, could lead to great clinical analysis. For example, the traces following different paths to pursue and meet the goal, age groups associated with those paths, paths likely to be followed in practice, i.e., the consensus sequence activities or backbone activities for performing IV Goal, etc.

The following few chapters will include the experiments performed and how the original expert model got revised multiple times before converging to a final model, followed by improvement in Activity Trace Dataset, statistical and clinical analysis on the results, plan libraries generation, and future scope of this framework.

6.4. Analysis #1 – Initial Study of IV Realization Algorithm and Revisions

This experiment was mainly to study and analyze the expert model and get clarifications from the medical experts. For accomplishing a goal, the algorithm should have start and endpoints defined. The algorithm's start point could be any activity from the goal list, and the endpoint would be the resuscitation activity that will denote whether the goal is met or not. Some critical questions were asked to the experts that led to the revision of the IV realization algorithm. Below were some of the necessary analyses and thoughts on the original version of the IV Algorithm.

- As per the original algorithm shown in Figure 5., the determination of goal being met is only decided based on activity “IV Confirmation” as “Successful,” but this
is not consistent throughout the branches. There are some leaf nodes like the activity “Drill to Skin - IOP,” after which no confirmation of the goal is done.

- Further, it was noticed from the traces that there is no resuscitation activity “IV Confirmation” in the goal list and Activity Trace Dataset which helps determine if the goal is met. The only closest resuscitation activities that match this name were activity “IV Placement Confirmation” and activity “IV Placement.”

- Another essential aspect was about the decision points (colored diamonds), which have context defined. Based on these context attributes, the algorithm is either followed left or right or bottom. But it was found that there were no context attributes given in the Activity Trace Dataset that could help determine the branches and the sequence of resuscitation activities to follow.

- The resuscitation activity box present to the left of the brown box has activities “Immediate Drill to Skin - IOP with simultaneous IV Placement” being performed. It was unclear whether this set of two resuscitation activities can be performed simultaneously or individually, one after the other in sequence.

- It was also unclear about resuscitation activity “IV Placement Attempt x3 in 3 minutes” as there needs to be a deciding factor about when to stop the IV attempt and what basis it should stop.

- Lastly, the meaning of other unfinished boxes which are visited if activities “IV Placement or IV Confirmation” is “Unsuccessful” is not clearly understood.

Based on the above thoughts, experts revised the algorithm to make it more optimized and accurate, which could also conform with the data given in the Activity Trace Dataset,
as seen in Figure 6, which is the new version of the algorithm. Below were the vital conclusive points of the analysis based on the above thoughts:

- As per this new version, the resuscitation activity “IV Confirmation = Successful” check to determine the goal was added after dangling nodes like activity “Drill to skin.”

- Experts clarified that activity “IV Placement Confirmation” as successful should be considered as a goal met.

- As the context attributes that drive the workflow at the decision points (diamonds) are absent in Activity Trace Dataset, we could consider the different branches as different linear paths that the traces can follow to pursue the IV goal. These unique linear paths could be considered as plans that the computer-aided decision support system sends out as part of recommendations. Hence, based on the new version, we could see six different ways to meet the goal.

- The resuscitation activity box present to the left of the brown box in Figure 5, was replaced by a new box as shown in Figure 6, which is “Immediate Drill to Skin and simultaneous “IV Placement.” Thus, both resuscitation activities can occur in parallel while pursuing the IV Goal. In Activity Trace, we can see either of the resuscitation activities performed first followed by the other in sequence.

- Also, the team clarified that “IV Placement x3 times in 3 minutes” could be stopped by checking “IV Placement = Successful.”

- Lastly, the unfinished boxes’ means that the IV team is contacted to find other ways to establish an IV if the goal is not met.
Figure 6. Version 3 of the IV Realization Algorithm [Source: Workflow is provided by CNMC experts]
6.5. Analysis #2 – Identifying Linear Paths in IV Realization Algorithm

In the earlier chapter, we had arrived at a stable IV Realization Algorithm, as seen in Figure 6. The following steps were to identify the paths that each Activity Trace can follow in the IV Realization Algorithm. We consider the workflow model branches as linear paths since we do not have context attributes coded into Activity Trace Dataset. We identified six different branches or paths from the expert model shown in Figure 7.

- Path 1: IV Confirmation -> Goal Met (if Successful)
- Path 2: Drill to Skin -> IV Confirmation -> Goal Met (if Successful)
- Path 3: Drill to Skin and Simultaneous IV Placement -> IV Confirmation -> Goal Met (if Successful)
- Path 4: IV Placement (3x) -> IV Placement -> Goal Met (if Successful)
- Path 5: IV Placement (3x) -> IV Placement -> Drill to Skin -> IV Placement Confirmation -> Goal Met (if Successful)
- Path 6: IV Placement (3x) -> IV Placement -> Goal Met (if Successful)

These paths extracted can determine plan libraries which is the most critical aspect of building goal recommendation systems. These plans could be sent out to the primary healthcare providers during the trauma resuscitation process as part of recommendations by computer-aided decision support systems.

I developed the goal realization framework based on these paths derived from the workflow model (IV Realization Algorithm). The framework accepts the stream or sequence of resuscitation activities related to the IV goal from each Activity Trace. It passes it on through different paths of the algorithm defined above, and the IV goal can be met through any of the specified paths. If activity sequences do not follow a particular path,
we move on to the following path. For example, a trace meets a goal through Path 4 if it
does not follow any paths from 1 – 3. Path 1 is the initial IV confirmation check that
happens when a patient arrives at the trauma bay to check if they have an IV in place. Thus,
doctors can give medications or draw blood from the patient using an already established
IV.

Traces not conforming to any paths and do not meet the goal via any paths can be
investigated further. An investigation could lead to two possible conclusions: (1) Traces
not meeting the goal via any of these paths do not have an IV goal met in real life. (2)
Traces not meeting the goal via any of these paths but having an IV goal met in real life
(ground truth) can help create new plans or ways of meeting the IV goal and repair the
expert model or IV Realization Algorithm even further.

The statistical analysis like frequency of these paths followed and the number of traces
that follow these paths could help the experts determine the most common procedure that
providers follow in real life for establishing the IV. New insights and analysis can be done
based on the patients' age groups that follow these paths.

In the next section, we will discuss a framework developed that could determine the
Activity Traces where the IV goal is met in real (i.e., determine the ground truth) and
compare with the traces that meet the IV goal using the Realization Algorithm. It could
thus help find new paths (deviations/errors) and optimize the IV algorithm.
Figure 7. Linear Paths identified from Version 3 of the IV Realization Algorithm

[Source: Workflow is provided by CNMC experts]
6.6. Framework to Determine Ground Truth

The goal realization framework developed in the earlier section needs to be validated, and there needs to be some metrics to measure the framework's accuracy. The best possible way to determine the framework's accuracy is by comparing the traces that meet the IV goal via realization algorithm and real-life medical practice. For example, if a goal is met via the realization framework, it must also be met in real (ground truth), and hence we can thus validate the accuracy of the framework. Lower the accuracy of the framework – higher is the chance that the realization algorithm does not adhere to real-life medical practice, which needs to be optimized or repaired.

There were naive two ways to get the ground truth of the IV Goal from Activity Trace Dataset:

- The medical experts who had coded Activity Trace Dataset revisit the logs one by one and mark the traces and instances where the IV goal is met.
- View the video for each of the Activity Trace Dataset and mark those traces where the IV goal is met.

The problem with both approaches to determine the ground truth is that it is a time-consuming activity where the medical team goes through event logs or video reviews of more than 260 Activity Traces individually. As it was not feasible for the medical team to find ground truth by increasing the workforce, the problem was viewed as an engineering problem.

The medical team that codes Activity Trace Dataset had their definition of meeting an IV goal. Suppose either of the resuscitation activities – “IV Placement or IV Placement Confirmation” is “Successful” while pursuing the IV Goal. In that case, we can conclude
that the IV goal is met for that trace. Using this definition, I had developed a framework to
determine the ground truth to find instances where the IV goal is met in real.

The approach taken was to traverse through each trace and extract resuscitation
activities based on the definition of ground truth, i.e., activities IV Placement and IV
Placement Confirmation, and check if those activities are labeled as “Successful” or not.
Traces having this definition met can be marked as IV Goal met and could be compared
with the realization algorithm results. This framework could be easily extended to other
medical goals by incorporating the definition of the ground truth for other medical goals,
thus making it reusable.

6.7. Analysis #3 – Experiment 1 using Realization Algorithm

This chapter will discuss the results of the ground truth and compare it with the first
experimental results from the IV Realization Algorithm to determine the accuracy of the
algorithm/framework.

As mentioned in Table 2, results of the first experiment of Realization Algorithm, there
were 265 total Activity Traces where 188 traces had IV goal “pursued.” The Goal
Realization Framework detected 44 traces where the IV goal is “met” via the defined paths
(1 – 6). Further, the ground truth framework that determines the traces where the goal is
met in “real” during resuscitations had detected 176 traces. Upon comparing the
Realization Framework results with ground truth, the IV goal in 132 traces (176 – 44) were
not detected via any paths (1 – 6) of the realization framework. This total percentage of
traces that were not detected constitutes 75%, and thus, the accuracy of the
algorithm/framework is just 25% accurate.
<table>
<thead>
<tr>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Activity Trace Dataset</td>
<td>265</td>
</tr>
<tr>
<td>Total Activity Trace Dataset having IV goal pursued</td>
<td>188</td>
</tr>
<tr>
<td>Activity Traces having IV goal met via Realization Framework</td>
<td>44</td>
</tr>
<tr>
<td>Activity Traces having IV goal met in real (Ground Truth)</td>
<td>176</td>
</tr>
</tbody>
</table>

Table 2. Results of Experiment 1 using Realization Framework

Suppose we use this expert model to build recommendations systems that will send recommendations or plans of action to healthcare providers while performing the IV Goal during the trauma resuscitation process. In that case, the consequences will be much more adverse. There will always be a high risk of patients' death because they will not send correct plans to doctors using these systems. Hence, the only way to improve the accuracy is by analyzing the Activity Trace Dataset with an IV goal met in practice but did not have an IV goal met while using the realization framework.

Upon reviewing the traces while running the realization framework, several observations and conclusions were made after discussion with the medical team:

- 5 traces had an IV goal met twice in a single trace which meant the IV goal could be performed and met more than once during trauma resuscitations.
- 129 traces had to start with resuscitation activity “IV Placement,” which is why it did not follow the realization algorithm because the first IV confirmation check was not done after the patient had arrived in the trauma bay. It led to a question of whether the IV confirmation check needs to be done in each trace mandatorily or
should be done with either activity “IV Placement or IV Placement Confirmation = Successful.” Medical experts expressed their views that it is not mandatory to have an IV confirmation check after a patient arrives in the trauma bay. There are high chances that IV should be established for access multiple times even though a patient had an IV placed before arrival.

- 59 traces had IV confirmation checks after the patient had arrived at the trauma bay.
- There were few traces detected that had activity IV Placement Confirmation labeled as “Complete” instead of “Successful.” Experts reviewed those traces and modified the way of confirming an IV goal being met. The change made in the realization framework and algorithm to incorporate this inconsistency in coding was to check resuscitation activity “IV Placement Confirmation” as “Successful or Complete.”
- Many IV resuscitation activities and their labeled attributes like Successful, Unsuccessful, or Complete were not recognized by the framework in many traces while they passed through the framework. It was mainly because of the coding errors or inconsistency. Examples of such inconsistency/ errors in Activity Trace Dataset were – some attributes/ resuscitation activities were coded in lowercase and some in upper case. Hence, the trace did not match with resuscitation activity names from the IV goal list. Therefore, the framework was modified further to make it case insensitive, i.e., convert all of them to uppercase (or lowercase) before comparing resuscitation activities and attributes.
- One important observation was that few traces had IV-related activities even after the goal was met through the plans/paths. These remaining resuscitation activities were IV attempts that were made in the patients. Medical experts reviewed those
traces and concluded that if none of the paths is followed (Path 1 – 6), doctors try to place an IV until the goal is met or the mission is aborted. It is part of the “Need for trauma labs” and led to the addition of a new path, i.e., Path 7 in the realization algorithm or expert model and thus in the Realization Framework.

Thus, the updated IV Paths are derived from the modified expert model, as shown in Figure 8. Version 4 of IV Realization Algorithm that needed to be incorporated into the framework are:

- Path 1: IV Confirmation -> Goal Met (if Successful)
- Path 2: Drill to Skin -> IV Confirmation -> Goal Met (if Successful)
- Path 3: Drill to Skin and Simultaneous IV Placement -> IV Confirmation -> Goal Met (if Successful)
- Path 4: IV Placement (3x) -> IV Placement -> Goal Met (if Successful)
- Path 5: IV Placement (3x) -> IV Placement -> Drill to Skin -> IV Placement Confirmation -> Goal Met (if Successful)
- Path 6: IV Placement (3x) -> IV Placement -> Goal Met (if Successful)
- Path 7: Keep on trying to place IV (IV Placement) until successful
Figure 8. Version 4 of the IV Realization Algorithm and Linear Paths [Source: Workflow is provided by CNMC experts]
6.8. Analysis #4 – Experiment 2 using Realization Algorithm

In the previous chapter, we looked at the first experimental results and made some observations. Upon analyzing the results and observations and discussion with medical experts, few conclusions were made, followed by some essential changes in the realization algorithm. We also observed inconsistency and problems in data due to which our framework had to modify to increase the accuracy even further. This chapter will discuss and analyze the results from the second experiment that was performed using the revised realization framework and algorithm.

As mentioned in Table 3, results of the second experiment using Realization Algorithm, there were 265 total Activity Traces where 188 traces had IV goal “pursued.” The Goal Realization Framework, modified based on the results, conclusions, and observations of the previous chapter, detected a total of 173 traces where the IV goal is “met” via the paths (1 – 7). As compared to the first experiment, the total traces where the IV goal is detected via the goal realization framework increased from 44 to 173. Upon comparing the Realization Framework results with that of ground truth, the IV goal was not detected in only 3 traces (176 – 173) via any paths (1 – 7) of the realization framework. The total percentage of traces not detected fell from 75% to 1.7%, i.e., the accuracy of the framework/algorithm increased from 25% to 98.29%.

<table>
<thead>
<tr>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Activity Trace Dataset</td>
<td>265</td>
</tr>
<tr>
<td>Total Activity Trace Dataset having IV goal pursued</td>
<td>188</td>
</tr>
<tr>
<td>Activity Traces having IV goal met via Realization Framework</td>
<td>173</td>
</tr>
</tbody>
</table>
Activity Traces having IV goal met in real (Ground Truth) | 176

Table 3. Results of Experiment 2 using Realization Framework

This significant increase in the framework's accuracy and model was just because of the modifications made in implementing the goal realization framework and goal realization algorithm (expert model).

But several observations and conclusions were made based on the findings from the second experiments as well:

- 37 traces have IV Goal met more than once, which is perfectly fine in a real-life case because IV access needs to be established multiple times for various reasons like transfusing blood, giving medications, drawing blood for lab tests, etc.

- There were 10 traces detected where activity IV Placement was unlabeled, and 13 traces were detected where activity IV Placement Confirmation was unlabeled. Medical experts reviewed the video of those traces and cleaned the data. It not only improved the data quality but also will improve the accuracy of the recommendation system.

- A total of 6 traces were detected that followed some realization algorithm paths and met the goal. But some resuscitation activities were present, which did not follow the paths. One common reason was an IV Confirmation check was done every time after the “Need for trauma labs,” i.e., after Path 7. It led to a change in algorithm and framework and introduced a new path, i.e., IV Confirmation check, which was missing after Path 7, where we make attempts to place IV until its successful or goal is aborted.
Thus, the updated IV Paths are derived from the modified expert model, as shown in Figure 9. Version 5 of IV Realization Algorithm that needed to be incorporated into the framework are:

- Path 1: IV Confirmation -> Goal Met (if Successful)
- Path 2: Drill to Skin -> IV Confirmation -> Goal Met (if Successful)
- Path 3: Drill to Skin and Simultaneous IV Placement -> IV Confirmation -> Goal Met (if Successful)
- Path 4: IV Placement (3x) -> IV Placement -> Goal Met (if Successful)
- Path 5: IV Placement (3x) -> IV Placement -> Drill to Skin -> IV Placement Confirmation -> Goal Met (if Successful)
- Path 6: IV Placement (3x) -> IV Placement -> Goal Met (if Successful)
- Path 7: Keep on trying to place IV (IV Placement) until successful
- Path 8: IV Placement Confirmation -> Goal Met (if Successful)
Figure 9. Version 5 of the IV Realization Algorithm and Linear Paths [Source: Workflow is provided by CNMC experts]
6.9. Analysis #5 – Experiment 3 using Realization Algorithm

In the previous chapter, we looked at the second experimental results and made some observations. Upon analyzing the results and statements and discussion with medical experts, few conclusions were made, followed by some critical changes in the realization algorithm, i.e., the addition of a new path (Path 8). We also observed coding errors in the data, i.e., unlabeled resuscitation activities IV Placement and IV Placement Confirmation, for which the team had reviewed videos and corrected the dataset. This chapter will discuss and analyze the results from the third experiment that was performed using the modified realization framework and algorithm.

As mentioned in Table 4, results of the third experiment using Realization Algorithm, there were 265 total Activity Traces where 188 traces had IV goal “pursued.” After modifying the framework and correcting the dataset, 176 traces were detected where the IV goal is “met” via the paths (1 – 8). As compared to the second experiment, total traces where the IV goal is detected via the framework increased from 173 to 176. Upon comparing the Realization Framework results with that of ground truth, the IV goal was detected in all 176 traces. The total percentage of traces not detected fell from 1.7% to 0%, i.e., the accuracy of the framework/algorithm increased from 98.29% to 100%.

<table>
<thead>
<tr>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Activity Trace Dataset</td>
<td>265</td>
</tr>
<tr>
<td>Total Activity Trace Dataset having IV goal pursued</td>
<td>188</td>
</tr>
<tr>
<td>Activity Traces having IV goal met via Realization Framework</td>
<td>176</td>
</tr>
</tbody>
</table>
Activity Traces having IV goal met in real (Ground Truth)  176

| Table 4. Results of Experiment 3 using Realization Framework |

As the model accuracy is now 100%, the realization algorithm or the expert model could design the recommendation systems. The system will be bound to send out correct action plans during the resuscitation process because the number of traces detecting IV goals via algorithm/framework matches with the ground truth now.

There were a few observations and conclusions made after this experiment as well:

- 186/188 traces had followed all the realization algorithm paths “completely.” There were two traces that “partially” followed the realization algorithm and its paths. Because the goal was detected in the initial sequence of resuscitation activities. But as the IV goal can be pursued more than once, there are sub-sequences of resuscitation activities that do not follow any paths (1-8).

- After analyzing the sub-sequences of the two traces that do not follow the algorithm, we found that sequences do not make sense for one of the traces, i.e., the procedure followed in medical practice.

- For the other trace, new IV resuscitation activities were detected in the Activity Trace Dataset that was not part of the realization algorithm. The resuscitation activities detected were – Anatomy Ided, Local Anesthesia, and Skin Incision. As these resuscitation activities are absent in paths identified, i.e., the realization algorithm, medical experts reviewed the Activity Trace Dataset and video to determine whether this sub-sequence should be added to the realization algorithm or not. Upon reviewing the trace and video, experts concluded that these sub-
sequences that do not conform to the realization algorithm should not be included as a new path in the workflow as these are the resuscitation activities performed in the rarest case.

Hence, the algorithm/model that we converged to after multiple revisions were observed to be very accurate after performing experiments on Activity Trace Dataset and verifying it with the ground truth. The next chapter describes the analysis of multiple IV attempts followed in Activity Trace Dataset with age as an essential factor.

6.10. Analysis #6 – IV Attempts Analysis with Age as Factor

In the previous chapter, I had discussed the results of experiment #3 and compared the accuracy of the goal realization framework to the ground truth. As the framework developed based on a repaired/optimized version of the expert model had an accuracy of 100%, the clinical team wanted to get insights into the frequency of traces following different realization algorithm paths.

As per the results from Experiment #3 described in Table 4., 188/265 traces had IV goal “pursued,” out of which 176 traces had IV Goal “met” via paths (1 – 8). The number of traces that had the goal “met” and detected by framework also matched the ground truth, i.e., the total traces having the goal met in “real.” But to get more insights regarding the IV placement attempts, statistics regarding the traces following different paths to meet the IV goal were needed.

I extracted the statistics (frequency) of the traces that follow different IV algorithm paths and met the goal. Table 5. shows the result of the same.
### Table 5. Trace Frequency following Different Paths of Realization Algorithm

<table>
<thead>
<tr>
<th>Path</th>
<th>Resuscitation Activity Sequence</th>
<th>Number of traces following the path</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IV Placement Confirmation</td>
<td>76</td>
</tr>
<tr>
<td>2</td>
<td>Drill to skin -&gt; IV Placement Confirmation</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Drill to skin and IV Placement -&gt; IV Placement Confirmation</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>IV Placement (3x) -&gt; IV Placement</td>
<td>124</td>
</tr>
<tr>
<td>5</td>
<td>IV Placement (3x) -&gt; IV Placement -&gt; Drill to Skin -&gt; IV Placement Confirmation</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>IV Placement (3x times) -&gt; IV Placement</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>IV Placement (until successful)</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>IV Placement Confirmation</td>
<td>4</td>
</tr>
</tbody>
</table>

Essential details of the patient are always captured by the clinical team, like age, weight, height, race, and ethnicity, etc., as part of the pre-arrival checklist. So, experts wanted to further explore the traces following different paths based on the age groups. Using the clinical team's data, I categorized the age groups and the number of traces in those age groups following different realization algorithm paths. Result table 6. shows the related statistics of traces following different paths categorized by age groups.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
<th>Path 5</th>
<th>Path 6</th>
<th>Path 7</th>
<th>Path 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 6. Traces following Realization Algorithm Paths Categorized by Age Groups

As per the result table 5., Path 4 was followed by most traces where we try to place IV three times until successful and then again confirm the IV placement in the end. Thus, there can be multiple attempts made on the patient for placing an IV before successfully placing the IV and confirming it. The clinical team wanted to have more insights about patients taking single successful IV attempts and multiple IV attempts (whether leading to success or not) based on the age groups of patients age between 0-1 (age <12months) and patients age higher than 12 months (age > 12 months).

I had later generated results using the logs from the framework and categorized the number of traces with the patient’s age between 0-12 months and greater than 12 months.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>0-12 months</th>
<th>&gt;12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single IV Attempt</td>
<td>6</td>
<td>80</td>
</tr>
<tr>
<td>Multiple IV Attempt</td>
<td>14</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 7. Age Distribution towards Single v/s Multiple IV Attempts
As per Table 7. age distribution towards single IV attempts and multiple IV attempts, the proportion of patients taking a single IV attempt is significantly higher when they are older than 12 months. While patients less than 12 months might have to undergo several IV attempts before placing it successfully.

6.11. Analysis #7 – Experiment 4 using Realization Algorithm (Additional Dataset)

Experts keep on enriching the dataset by coding more real-life trauma resuscitation traces, also called Activity Trace Dataset. This new addition of Activity Traces to the dataset could discover new paths in the realization algorithm and eventually in the expert workflow model.

The number of additional traces coded by the experts was 6, thus making the total count of Activity Trace Dataset 271. While running the fourth experiment on 271 Activity Traces, a few observations and conclusions were made:

- 92 traces did not have resuscitation activity IV Placement Confirmation that could confirm the goal being met. And the goal was still met via algorithm even in the absence of IV confirmation because of Path 4, i.e., IV Placement (3x times) -> IV Placement -> Goal Met (if Successful) where IV goal is said to meet if any of the IV Placement is Successful.

- Hence, experts repaired the algorithm by adding an IV Confirmation check after every successful IV attempt in paths 4, 6, and 7. Thus, the paths also changed further.

- Moreover, experts reviewed a few videos from 92 traces where IV confirmation activity is absent, and the goal was met via path 4 to find possible ways of
confirming the IV goal. The team later defined a new way of confirming an IV upon reviewing the videos. Experts concluded that resuscitation activity IV Confirmation could be any of the following activities – IV Placement Confirmation, IV Bolus Given, IV Bolus Connected, IV Bolus Disconnected, Blood Drawn, and Pain Medication. If any of the mentioned resuscitation activities are “Successful,” then a goal is met. This new definition changed the goal realization framework and the expert algorithm.

- But we found more than 200 traces where these new additions of resuscitation activities are unlabeled, i.e., not marked as “Successful/Unsuccessful.” Based on theoretical knowledge and practical experience, experts decided to consider unlabeled IV Bolus Given and Pain Medications activities as “Successful” by default. Because bolus and medication resuscitation activities only happen if the IV is established already. So, these two unlabeled resuscitation activities can indeed confirm that the IV goal is met.

Thus, the updated IV Paths are derived from the modified expert model, as shown in Figure 10. Version 6 of IV Realization Algorithm and needed to be incorporated into the framework are:

- Path 1: IV Confirmation -> Goal Met (if Successful)
- Path 2: Drill to Skin -> IV Confirmation -> Goal Met (if Successful)
- Path 3: Drill to Skin and Simultaneous IV Placement -> IV Confirmation -> Goal Met (if Successful)
- Path 4: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful)
- Path 5: Drill to Skin (If IV goal not met via path 4) -> IV Confirmation -> Goal Met (if Successful)
- Path 6: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful)
- Path 7: IV Placement (until IV attempt is successful) -> IV Confirmation (If any IV attempt is successful) -> Goal Met (if successful)
- Path 8: IV Confirmation -> Goal Met (if Successful)

NOTE: From the new definition, the resuscitation activity IV Confirmation mentioned in the above plans constitutes – IV Placement Confirmation, IV Bolus Given, IV Bolus Connected, IV Bolus Disconnected, Pain Medication, and Blood Drawn.

The next chapter will focus on the final experiment done on the latest version, i.e., version 6 of the realization algorithm and the corresponding framework.
Figure 10. Version 6 of the IV Realization Algorithm and Linear Paths [Source: Workflow is provided by CNMC experts]
6.12. **Analysis #8 – Final Experiment using Realization Algorithm**

This chapter will discuss the final experiment results on the realization algorithm developed after several revisions using the corresponding realization framework that evolved after each experimentation, results, and analysis. As per the previous chapter, we had a total of 8 paths defined along with a new definition of IV confirmation.

As mentioned in Table 8, the final experiment results using the Realization Algorithm, there were 271 total Activity Traces where 245 traces had IV goal “pursued.” The goal realization framework detected 225 traces having the IV goal “met” via paths (1 – 8). Further, the framework that determines ground truth to get total traces where the IV goal is met in “real” also detected 225 traces having the IV goal met. Thus, the final model's accuracy is 100% because all the traces detected via the realization framework match the ground truth.

<table>
<thead>
<tr>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Activity Trace Dataset</td>
<td>271</td>
</tr>
<tr>
<td>Total Activity Trace Dataset having IV goal pursued</td>
<td>245</td>
</tr>
<tr>
<td>Activity Traces having IV goal met via Realization Framework</td>
<td>225</td>
</tr>
<tr>
<td>Activity Traces having IV goal met in real (Ground Truth)</td>
<td>225</td>
</tr>
</tbody>
</table>

Table 8. Results of Final Experiment using Realization Framework.

6.13. **Analysis #9 – Statistical Analysis on the Final Experiment**

Now since the model/realization framework is 100% accurate, experts wanted some statistical results like the number of times a goal was pursued via a path, the number of
times goal was met via a path, traces following different paths of the algorithm to meet the goal and so on. These results could greatly benefit experts to deep dive into the results and make some conclusions. To recall different paths of our algorithm based on the final version (Version 6) of an expert model derived in “Analysis #7 – Experiment 4 using Realization Algorithm” chapter, the paths were:

- Path 1: IV Confirmation -> Goal Met (if Successful)
- Path 2: Drill to Skin -> IV Confirmation -> Goal Met (if Successful)
- Path 3: Drill to Skin and Simultaneous IV Placement -> IV Confirmation -> Goal Met (if Successful)
- Path 4: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful)
- Path 5: Drill to Skin (If IV goal not met via path 4) -> IV Confirmation -> Goal Met (if Successful)
- Path 6: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful)
- Path 7: IV Placement (until IV attempt is successful) -> IV Confirmation (If any IV attempt is successful) -> Goal Met (if successful)
- Path 8: IV Confirmation -> Goal Met (if Successful)

- NOTE: Resuscitation activity IV Confirmation mentioned in the above plans constitutes of – IV Placement Confirmation, IV Bolus Given, IV Bolus Connected, IV Bolus Disconnected, Pain Medication, and Blood Drawn.
I added features for generating statistics into the goal realization framework. Table 9 shows the final experiment's statistical results after adding features in the framework regarding the same. As per table 9 were the observations and conclusions made:

- Total traces that follow different paths for meeting the IV goal are 292 (183+1+101+7), which is higher than the total number of traces where the IV goal is met, i.e., 225. It is because a single trace might have an IV goal met via the same or different paths, as the IV goal can be pursued and met multiple times in medical practice.

- The goal pursued via Path 1 was 731 times, and the goal met was 633 times (86.6%).

- The goal pursued via Path 2 was 1 time, and the goal was met 1 time (100%).

- The goal pursued via Path 3 was 0 times, and the goal was met 0 times.

- The goal pursued via Path 4 was 174 times, and the goal was met 107 times (61.5%).

- The goal pursued via Path 5 was 1 time, and the goal was met 0 times (0%).

- The goal pursued via Path 6 was 42 times, and the goal was met 7 times (16.7%).

- The goal pursued via Path 7 was 35 times, and the goal was met 0 times (0%).

- The goal pursued via Path 8 was 0 times, and the goal was met 0 times.

- Thus, based on the above numbers, we can say that it is more likely to meet the IV goal via path 1 and path 4, i.e., IV confirmation, and by attempting to place IV followed by confirming the same.

- Also, we see goal pursued via path 1 is 731 times greater than the total number of traces (271). Because some traces might have multiple IV placed, the IV goal can
be met numerous times in a single trace. As Path 1 only includes activity “IV Placement Confirmation,” it is more likely that this path would be pursued multiple times to give medications, draw blood or give bolus to the patient, which confirms whether an IV is placed or not.

- There are few potential reasons why the goal is pursued 731 times via path 1 but only met 633 times:
  - This path confirms whether the patient has IV established or not before arriving at the trauma bay and during the resuscitation process.
  - Hence, some traces might not have IV placed before arriving at trauma bay, so the goal will not meet via this path.
  - Also, there would be traces where IV is not placed correctly, and hence the goal is not met during the trauma resuscitation process via Path 1. Because if IV is not placed appropriately, then – Blood cannot be drawn from the patient, Medications cannot be given to the patient, etc., which indicates that the IV goal is not met.
  - The number of traces having IV check after arrival is 136, i.e., 136 patients might have an IV before arriving in trauma bay.
  - It is also observed that 243/245 traces where IV is pursued follow the algorithm “completely,” i.e., 99.2%. The two traces that do not follow the algorithm “completely” were because of exceptional reasons. One of the traces had redundant activities. The other trace resuscitated activities like Anatomy Ided, Local Anesthesia, Skin Incision performed for IV goal but are not part of realization algorithm because these are the rarest scenarios.
- IV goal is met in 225/245 traces where IV is pursued, i.e., 91.83% of the traces had IV access established.

The statistical results could lead to great insights into how a goal is pursued and met in practice during the trauma resuscitation process and determine the common ways or general practice of meeting the IV goal. Other general stats can give an overview of the IV goal across all the Activity Trace Dataset.

<table>
<thead>
<tr>
<th>Category</th>
<th>Result Description</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traces following different paths of the algorithm to meet IV Goal</td>
<td>Total traces that follow path 1</td>
<td>183</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 4</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total traces that follow path 8</td>
<td>0</td>
</tr>
<tr>
<td>Frequency of paths visited for pursuing IV Goal</td>
<td>Goal Pursued via Path 1</td>
<td>731</td>
</tr>
<tr>
<td></td>
<td>Goal Pursued via Path 2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Goal Pursued via Path 3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Goal Pursued via Path 4</td>
<td>174</td>
</tr>
<tr>
<td></td>
<td>Goal Pursued via Path 5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Goal Pursued via Path 6</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Goal Pursued via Path 7</td>
<td>35</td>
</tr>
<tr>
<td>Frequency of paths via which IV goal is met</td>
<td>Goal Pursued via Path 8</td>
<td>0</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------</td>
<td>---</td>
</tr>
<tr>
<td>Goal Met via Path 1</td>
<td>633</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 4</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 6</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 7</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Goal Met via Path 8</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Stats</th>
<th>Traces having IV check after arrival</th>
<th>136</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traces that follow all paths of the expert model</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>Traces that follow some paths of the expert model</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Traces that do not follow any paths of the expert model</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Traces having IV goal met</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td>Traces having IV goal pursued</td>
<td>245</td>
</tr>
<tr>
<td></td>
<td>Total number of Activity Trace Dataset</td>
<td>271</td>
</tr>
</tbody>
</table>

Table 9. Statistical Results from Final Experiment

This chapter will discuss how we can generate plan libraries using the paths identified in the final version of the realization algorithm for a trace to follow and meet an IV goal. These plan libraries are plans of action that the recommendation system will send out during trauma resuscitations to the doctors. Hence, designing systems with correct plans is very vital. We will also compare the plan libraries that the popular process mining tool like DISCO generates with ones detected by using a realization framework.

Using the realization algorithm, we detected 8 different paths via which the IV goal can be pursued and met. These 8 paths could help us determine plan libraries for designing recommendation systems. Table 10. shows the 8 different ways from the realization algorithm and the plan libraries determined from each of those paths:

<table>
<thead>
<tr>
<th>Paths from Realization Algorithm (Expert Model)</th>
<th>Plan Libraries Determined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path 1, Path 8: IV Confirmation -&gt; Goal Met (if Successful)</td>
<td>IV Confirmation</td>
</tr>
<tr>
<td>Path 2: Drill to Skin -&gt; IV Confirmation -&gt; Goal Met (if Successful)</td>
<td>Drill to Skin -&gt; IV Confirmation</td>
</tr>
<tr>
<td>Path 3: Drill to Skin and Simultaneous IV Placement -&gt; IV Confirmation -&gt; Goal Met (if Successful)</td>
<td>Drill to Skin and IV Placement -&gt; IV Confirmation</td>
</tr>
<tr>
<td></td>
<td>IV Placement (successful) -&gt; IV Confirmation</td>
</tr>
</tbody>
</table>
Path 4, Path 6: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful)  

Path 5: Drill to Skin (If IV goal not met via path 4) -> IV Confirmation -> Goal Met (if Successful)  

Path 7: IV Placement (until successful) -> IV Confirmation -> Goal Met (if Successful)  

| Path 4, Path 6: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful) | IV Placement (unsuccessful) -> IV Placement (successful) -> IV Confirmation |
| Path 5: Drill to Skin (If IV goal not met via path 4) -> IV Confirmation -> Goal Met (if Successful) | Drill to Skin -> IV Confirmation (If goal not met via Path 4) |
| Path 7: IV Placement (until successful) -> IV Confirmation -> Goal Met (if Successful) | IV Placement (x times) -> IV Confirmation |

Table 10. Goal Realization Paths and their Plan Libraries

DISCO (https://fluxicon.com/disco/) is a popular process mining tool that helps in automated process discovery, generates plans of sequences of resuscitation activities followed across Activity Traces, and creates a workflow model based on the medical process logs. Using the DISCO tool on 271 Activity Trace Dataset, we detected 144 different activity sequence variants.

Upon sharing the results of 144 variants of resuscitation activity sequences with the medical team, few observations and conclusions were made after comparing with plan libraries determined from the Realization Algorithm:

- It was fairly impractical to go through each variant of DISCO resuscitation activity sequences and relate them to the real-world medical procedure to determine which
variant could be included as a plan library while designing recommendation systems.

- As observed in our earlier experiments, a goal can be pursued multiple times in an Activity Trace. But DISCO does not consider that and generates all the sequence of resuscitation activities (variants) followed while performing the IV goal across 271 traces. Ideally, these sequences could be divided into sub-sequences each time a goal is met to determine the exact plans. DISCO lacks this functionality compared to the realization framework.

- The 8 paths in IV Goal realization are much more granular and precise and hence plan libraries detected were accurate and much easier to follow.

- DISCO does not consider resuscitation activities IV Bolus Given, IV Bolus Connected, IV Bolus Disconnected, IV Placement Confirmation, Pain Medication, and Blood Drawn as “IV confirmation.” Thus, the variants/sequences' lengths are very high, due to which determining a plan library is complex. As the realization framework considers the six resuscitation activities for IV Confirmation as a single activity, the plans are much simpler and easier to understand.

6.15. Reusability and Extensibility of Realization Framework for other Medical Goals

In the earlier chapter, we discussed the IV realization algorithm and how an IV goal can be performed and met (i.e., different paths in the IV algorithm that can be followed). We also developed the realization framework that can emulate an IV realization algorithm, ran several experiments, performed analysis, repaired/optimized the expert model (i.e., realization algorithm to a stable version), and later generated the plan libraries. The high-
level deficiencies found in each version of the model before arriving at a stable version were:

- In Version 1, the model was not formed based on the activity names mentioned in Activity Trace Dataset. Hence, the 2nd version of the algorithm was developed.

- In Version 2, the IV was not confirmed after few nodes (dangling nodes), the resuscitation activity name for meeting a goal was not clear, when should the process of attempting an IV was not mentioned clearly, etc. It led to the creation of version 3 of the algorithm.

- Using Version 3, we developed the goal realization framework by considering all the branches as linear paths. After performing a conformance check using Activity Trace Dataset, we found that the IV can be placed whether or not the patient has an IV before arrival or not. Also, it found that the goal can be performed multiple times, followed by introducing the new Path 7 in the algorithm where doctors keep on trying to place an IV until it is successful or the attempt is aborted. Thus, version 3 was optimized to form version 4.

- Using version 4, we found a new path, i.e., Path 8, which confirms IV at the end of Path 7, i.e., after experts keep on trying to place an IV until it's successful. Thus, we repaired the framework and algorithm to include this path to form version 5.

- After receiving an additional dataset from the medical team, we performed the conformance check again on all 271 traces and found several many cases didn’t have resuscitation activity IV Placement Confirmation. The investigation followed led to the optimization of the framework and algorithm to consider activity IV Confirmation as either of the following resuscitation activities – IV Placement
Confirmation, Blood Drawn, IV Bolus Connected, IV BolusDisconnected, Pain Medications, and IV Bolus Given for confirming IV. Thus arriving at a stable version, i.e., Version 6 of the expert model.

Similar deficiencies can be found by performing conformance check experiments and analyses for other medical goals. Thus, we could arrive at a stable version of the expert model or goal realization algorithm by addressing those deficiencies.

Due to excellent realization framework results for the IV goal and its accuracy, the framework was generalized so that the goal realization algorithm for other goals can be developed (similar to the IV realization algorithm) and integrated. Also, activity sequences for that goal could be extracted and passed through the new goal realization algorithm for conformance check. It is modular to easily add functions to create custom output files, filter traces for whom we don’t want to perform conformance checks, etc., for different medical goals.

Hence, the framework could easily be extended and reused by implementing realization algorithms for other medical goals similar to the IV realization algorithm like a plug-n-play device.

7. Interpreting Medical Processes using Workflow Modelling

7.1. Introduction

In the previous section, we had developed a goal realization framework based on the expert model. We did a conformance check against the Activity Trace Dataset, i.e., the medical process logs. After multiple experiments and revisions of the expert model, the developed framework had an accuracy of 100% in conformance check against the ground
truth. Moreover, we had also extracted the plan libraries using the realization framework, which can be sent as recommendations from the recommendation system. But analyzing these plans and expert models using workflow models that can be interpretable to the clinical team would be an essential factor to consider.

This section will first discuss automatic workflow discovery algorithms \cite{7} and the need to develop the Dataset Generation Framework for workflow discovery, followed by the implementation details and its future scope. Using the dataset generated from the framework, we would introduce the workflow model developed using DISCO and the PIMA algorithm \cite{4} and compare it with the expert model.

### 7.2. Automatic Workflow Discovery Algorithms and Tools

Workflow Models are created using process logs to interpret the procedure or pattern followed in practice while pursuing a goal. Several algorithms and tools have recently been developed to generate the workflow models. These algorithms typically use process mining techniques to create process maps or workflows. DISCO (https://fluxicon.com/disco/) is one such tool that produces the process maps using the event logs. But the workflows that DISCO generates are complicated to comprehend and analyze because these workflow models are typically like spaghetti-based models. Figure 11. shows one such example of a spaghetti model. Also, DISCO does not filter out resuscitation activities whose frequency of occurrence is very low as those would be performed in exceptional scenarios and not in general practice. It adds ambiguity even further as the expert model does not include resuscitation activities in rare scenarios.
Figure 11. Example of a Spaghetti Model

Workflow discovery algorithms like PIMA [4] are developed to discover workflow models [7] that are easily interpretable. The model generated using the workflow discovery algorithm [7] is easy to follow because of the model's linear structure. It filters out resuscitation activities performed in rare scenarios and generates models with activities typically performed in the real world. Two essential steps while using workflow discovering algorithm are – (1) Alignment Matrix and (2) Generation of Workflow model from alignment matrix [7].

The alignment matrix is formed using the PIMA algorithm, i.e., “process-oriented iterative multiple alignments for medical process mining” [4]. This algorithm aligns activities across all the Activity Trace Dataset using the Needleman-Wunsch Multiple
Sequence Alignment algorithm. PIMA achieves the best sum of pair scores in $O(NL^2)$ compared to other trace alignment algorithms \[^{[4]}\]. The best workflow model is derived from an alignment matrix after multiple experiments and analyses that match the expert model. While deriving the best sequence and its workflow model from the alignment matrix, hyperparameters – Consensus Sequence Threshold and SPAN number play a vital role.

The trace alignment matrix has columns containing the resuscitation activities aligned after executing the multiple sequence alignment algorithm. Consensus columns correspond to the resuscitation activities with an occurrence probability of more than a predefined threshold (T). The consensus sequence activities formed are the backbone, i.e., resuscitation activities typically performed to pursue a medical goal. Other columns not part of consensus are non-consensus columns which might contain resuscitation activities that should be part of consensus but are dispersed in the alignment matrix. The spanning procedure helps incorporate activities from consecutive non-consensus columns into the model as “branches.” Previous work was done around performing multiple experiments for different CS thresholds and Span numbers to determine the best model \[^{[10]}\]. I will directly introduce the best model generated after performing similar experiments \[^{[10]}\], i.e., by varying the hyperparameters and comparing them with the expert model.

7.3. Dataset Generation Framework for Workflow Discovery

In the earlier chapter, I discussed details regarding tools and algorithms developed in recent times that could automatically discover workflows using process mining. Previously, medical experts would give a demo dataset or manually create it so that these tools and algorithms could understand, or engineers would generate a synthetic dataset for
these tools and algorithms. Activity Trace Dataset could be leveraged rather than developing synthetic data or manual data prone to human errors because determining workflows from real-life processes is always accurate and insightful.

I have developed a framework that could extract data related to specified medical goals from each Activity Trace using each goal’s activity list. Below are the fields extracted from each Activity Trace:

- Onset_time - Start time of an activity performed during resuscitation.
- Offset_Time – End times of an activity performed during resuscitation.
- Code – Activity name denoting the resuscitation activity performed.

Trace ID (Case ID) is extracted too from the filename of the trace. Extracted data is later processed and then transformed to a format that these algorithms and tools could understand to create workflow models and stored in a CSV log file. This CSV log file would contain the resuscitation activities performed for a specified goal with start and end times and the case id for each trace. Thus, extracted data in the form of a CSV log, which is the ground truth, can be imported into workflow discovery tools or algorithms.

Details regarding the dataset generated for the IV goal can be observed in Table 11. Out of 271 traces, IV is pursued in 245 traces. A total of 11 unique resuscitation activities were detected related to the pursuit of the IV goal, and that medical experts specified them in the activity goal list discussed in Section 4.2. The data processing and transformation step are mandatory before creating the log file because:

- Activity “IV Placement Confirmation” can be any of the following resuscitation activities – Blood Drawn, IV Bolus Connected, IV Bolus Given, IV Bolus Disconnected, IV Placement Confirmation, Pain Medication. These resuscitation
activities directly confirm whether the patient has an IV access established or not, i.e., an IV Goal is met or not.

- If we don’t perform process and transform data, the workflow models would turn out to be very complex (if generated using DISCO due to the spaghetti nature of the model) or very long (if generated via workflow discovery algorithm [7] due to linear nature of the model).

- Thus, to reduce the redundancy in workflow models, it would be appropriate to consider all these activities as one, i.e., resuscitation activity “IV Placement Confirmation” to indicate an IV goal's confirmation.

- This definition of “IV Confirmation” was also described in chapter 6.11. Analysis #7 – Experiment 4 using Realization Algorithm.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Activity Trace Dataset</td>
<td>271</td>
</tr>
<tr>
<td>Total traces having IV goal pursued</td>
<td>245</td>
</tr>
<tr>
<td>Unique resuscitation activities detected across 245 traces related to the pursuit of the IV goal</td>
<td>11 (IV Placement, Skin Incision, Drill to Skin, Local Anesthesia, Blood Drawn, IV Bolus Connected, IV Bolus Given, IV Bolus Disconnected, IV Placement Confirmation, Pain Medication, Anatomy Ided)</td>
</tr>
</tbody>
</table>
Unique resuscitation activities after processing and transforming data

| 6 (IV Placement, IV Placement Confirmation, Local Anesthesia, Skin Incision, Drill to Skin, Anatomy Ided) |

Table 11. Dataset Details for IV Goal extracted from Dataset Generation Framework

The framework developed for generating a dataset from real-life process logs can be easily extended and reused for other medical goals with inputs as Activity Trace Dataset and resuscitation activity list for each goal for extracting related resuscitation activities. Thus, this reusable framework would assist significantly in interpreting workflows created from real-life processes.

In section 6, i.e., goal realization framework, I had performed multiple experiments and analyses using the goal realization framework, which led to optimizing the expert model that the clinical team had initially generated using their theoretical knowledge. Since the model was optimized/repaired based on the ground truth (process followed in real life), it is much more accurate. We proved the accuracy of the model and framework by comparing it with the ground truth's outputs. Even though the stable version of the expert model is created, it is not easy to comprehend. Thus, to better interpret it, there are tools and algorithms developed to create interpretable workflow models.

The following chapters will derive the workflow model using DISCO and compare it with the expert model. We will also derive it using the workflow discovery algorithm directly using a defined threshold and span number and compare it with the expert model.
7.4. Comparing Workflow Model Generated using DISCO with Expert Model

The dataset generation framework introduced in the earlier chapter generates a dataset of how these algorithms and tools could understand and create interpretable workflows. Figure 12 shows IV workflow model generated using the DISCO (https://fluxicon.com/disco/).

![IV Workflow Model Generated using DISCO](image)

Figure 12. IV Workflow Model Generated using DISCO

Below is the analysis of why the workflow model derived using DISCO cannot be used for interpretation and compared with the expert model:

- The model formed using DISCO is very chaotic and hence making it complex to understand due to the spaghetti nature.
The exact sequence of resuscitation activities to follow for performing the IV goal cannot be determined after looking at this model.

As seen in figure 12., resuscitation activities like Anatomy Ided, Local Anesthesia, Skin Incision were not part of the optimized/repaired expert model (Figure 10. Version 6 of IV Realization Algorithm) but are present in this model. These resuscitation activities are performed in rare scenarios. Hence filtering the same from workflow is needed to resolve the ambiguity and only consider the backbone resuscitation activities contributing to a goal. DISCO lacks this feature of filtering infrequent activities performed in rarest scenarios and is not part of the expert model.

There are many loops and branches between resuscitation activities which adds more complexity for experts in interpreting the workflow. This complexity increases even further when more resuscitation activities for a medical goal are added to the model.

Thus, there needs to be a simplified model, making it easier to understand the medical processes. A better way to represent the workflow model would be a linear structure with no loops in it and using which exact sequence of activity to perform during resuscitation can be determined. In the next chapter, we will discuss the model generated using the workflow discovery algorithm \[^7\] that is linear and easier to interpret.

### 7.5. Comparing Workflow Model Generated using Workflow Discovery Algorithm with Expert Model

In the earlier chapter, the model generated using DISCO was very complex to interpret. Thus, we had discussed workflows generated using the workflow discovery algorithm \[^7\]
in chapter 7.2, which contains only the consensus activities, i.e., resuscitation activities performed typically in pursuit of a goal. The linear structure of the workflow makes it easier for experts to analyze and understand the medical process.

Related work on generating the best model using a workflow discovery algorithm \cite{7} that could match the expert model was done in “Reducing workflow model complexity for an automatic workflow discovery algorithm” \cite{10}. The best model was generated by varying the consensus sequence threshold and SPAN number discussed in chapter 7.2. Similarly, in this work, using multiple experiments by changing consensus sequence and SPAN \cite{10}, I had derived the model using a workflow discovery algorithm \cite{7} that matches best with the expert model, as seen in Figure 10. Version 6 of IV Realization Algorithm. Figure 13 shows the workflow model derived using a workflow discovery algorithm \cite{7} with Consensus Sequence Threshold and SPAN number selected as 40% and 5, respectively.

![Workflow Model derived using Workflow Discovery Algorithm](image)

**Figure 13. Workflow Model derived using Workflow Discovery Algorithm** \cite{7}
The model visible in Figure 13, derived from the workflow discovery algorithm [7] is easier to follow and understand. The blue ovals are the consensus sequence activities, i.e., backbone resuscitation activities typically performed for IV Goal and are included based on the defined consensus sequence threshold (40%). The white ovals are the resuscitation activities that are not part of the backbone but are equally crucial while pursuing an IV goal, and these are included based on Span number (5).

Below is the analysis of why the model derived with a consensus sequence threshold of 40% and a Span number of 5 matches the expert model. It makes more sense to compare with the expert model using the different paths/branches it constitutes.

- By referring to Table 10., we have 8 different paths that can be followed in the IV algorithm while performing the IV goal:
  - Path 1, Path 8: IV Confirmation -> Goal Met (if Successful)
  - Path 2: Drill to Skin -> IV Confirmation -> Goal Met (if Successful)
  - Path 3: Drill to Skin and Simultaneous IV Placement -> IV Confirmation -> Goal Met (if Successful)
  - Path 4, Path 6: IV Placement (3x unsuccessful attempts) -> IV Confirmation (If any IV attempt is successful out of 3) -> Goal Met (if Successful)
  - Path 5: Drill to Skin (If IV goal not met via path 4) -> IV Confirmation -> Goal Met (if Successful)
  - Path 7: IV Placement (until successful) -> IV Confirmation -> Goal Met (if Successful)

- By referring to the results of statistical analysis on the final experiment, i.e., Table 9., we see IV goal is pursued via Path 1 – 731 times, Path 2 – 1 time, Path 3 – 0
times, Path 4 – 174 times, Path 5 – 1 time, Path 6 – 42 times, Path 7 – 35 times and Path 8 – 0 times.

- The reason why the resuscitation activity “Drill to Skin” is not part of the workflow model, as seen in Figure 13, is that the goal is pursued via Path 2 – 1 time, Path 3 – 0 times, and Path 5 – 1 time which contains activity “Drill to Skin.” Thus, the CS threshold filters that resuscitation activity and its path from the workflow model.

- Since most of the paths followed while pursuing the IV goal are via Paths 1, 4, 6, and 7, the workflow model derived using the workflow discovery algorithm must contain these paths as part of the backbone, i.e., resuscitation activities typically performed for IV goal or branches.

- The path highlighted in Figure 14. Path 1 identification in Workflow Model shows that IV goal can be started by pursuing resuscitation activity IV Placement Confirmation, which confirms IV. It is Path 1 according to the expert model. Also, it is part of the workflow model because 731 times the goal is pursued via path 1.

Figure 14. Path 1 Identification in derived Workflow Model
- The path highlighted in Figure 15. Path 4 and 6 identification in Workflow Model, we can see that IV goal can be started directly by placing IV, i.e., activity IV Placement followed by activity IV Placement Confirmation. It is Path 4 according to the expert model. As the goal is pursued via Path 4 - 174 times, it needs to be the essential part of the workflow model.

- Since Path 4 and 6 are similar as per the expert model, and paths identified, we can consider the highlighted resuscitation activity sequence as the same for Path 4 and 6 as the goal is pursued via Path 6 - 42 times, and it needs to be included in the workflow model as highlighted below.

**Figure 15. Path 4 and 6 Identification in derived Workflow Model**

- Also, we have seen in section 6.10. about analysis on placing IV with single v/s multiple attempts and the age groups associated with it, IV Placement was
successful in larger age groups in a single attempt. Hence, the workflow model-derived and seen in Figure 15., has only one IV Placement attempt followed by IV Confirmation compared to what the path states, i.e., IV Placement (3x unsuccessful attempts) followed by IV Confirmation (if any attempt is successful). As most of the traces in Activity Trace fall into this category, i.e., where IV Placement is successful in the first attempt, the highlighted path in Figure 15. is correct.

The path highlighted in Figure 16. Path 7 identification in Workflow Model, we can see that IV goal can be pursued by placing IV, i.e., activity IV Placement until it is successful followed by activity IV Placement Confirmation. It is Path 7 according to the expert model. As the goal is pursued via Path 7 - 35 times, it needs to be the essential part of the workflow model.

![Figure 16. Path 7 Identification in derived Workflow Model](image)
As seen in Figure 17, there are resuscitation activities “IV Placement Confirmation” at the end present. After IV is placed on the patient, it can be confirmed multiple times and in numerous ways. The ways IV is confirmed were defined earlier, i.e., if any of the resuscitation activities “IV Placement Confirmation, IV Bolus Given, IV Bolus Connected, IV Bolus Disconnected, Blood Drawn and Pain Medication” is Successful. Also, IV can be confirmed multiple times because patients might be given Bolus and Medications various times, and Blood can be Drawn several times too during resuscitations.

Figure 17. Multiple IV Confirmations in derived Workflow Model

7.6. Workflow Model – DISCO v/s Workflow Discovery Algorithm

In the earlier chapter, we discussed that the workflow model derived using a workflow discovery algorithm [7] with a consensus sequence threshold of 40% and a span of 5 was the best model that can be used for interpretation by the clinical team. This claim was
backed by several analyses and results that were discussed in this part of the chapter. It is also better than the one generated by DISCO in chapter 7.4., Figure 12, as the model derived by using DISCO is very complex to interpret compared to the model derived using workflow discovery algorithm \([7]\). This chapter will shortly discuss why the workflow algorithm's models are easier to understand over DISCO using ideas from the previous work \([7]\).

As seen in table 12., we see many statistics related to the workflow models generated using DISCO and Workflow Discovery Algorithm \([7]\).

<table>
<thead>
<tr>
<th>Measures</th>
<th>DISCO</th>
<th>Workflow Discovery Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Resuscitation Activities</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Number of Resuscitation Activity Types</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Number of Branches</td>
<td>N/A</td>
<td>3</td>
</tr>
<tr>
<td>Number of Loops</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 12. Comparing Statistics of Models – Disco v/s Workflow Discovery Algorithm

Below are the key points as to why the model generated using Workflow Discovery Algorithm \([7]\) should be used for interpretation rather than the one generated from DISCO:

- While the number of resuscitation activities is nearly the same in both the models, we can see from Table 12 that the number of activity types in DISCO is higher because it doesn’t filter out activities infrequently performed across the Activity Trace Dataset. In contrast, the workflow discovery algorithm filters out and considers only the IV goal's backbone activities.
- The workflow discovery algorithm includes the same activity types in the model, indicating that the activity is performed numerous times in the traces.

- The number of branches in the DISCO model is significantly higher than the one generated from the algorithm, making it very difficult to interpret. Also, the exact number of branches from the DISCO model cannot be determined because it is not clear which paths are the branches and which are the backbone. However, in the model derived using workflow discovery algorithm [7], we see 3 branches (white-colored ovals) and the backbone activities (blue-colored ovals), making it easier to interpret.

- Moreover, the DISCO model has loops compared to the model derived using the workflow discovery algorithm [7], making it even more complex and spaghetti.

7.7. Including In-frequent Resuscitation Activities in Workflow Discovery Algorithm

Chapter 7.5 discussed models generated from workflow discovery algorithms [7] and how they can effectively interpret the medical processes and expert models. We also discussed that the developed models have filtered out activities that performed rarely using consensus sequence threshold as a function. But sometimes, experts might need to include few in-frequently performed activities in the model derived from the workflow discovery algorithm [7] because they might be important ones to be performed in pursuit of a goal. It is a spanning function that incorporates common but dispersed activities from the alignment matrix to the derived model. Hence, we can use the spanning process similarly to include the infrequent activities in the model. For example, the activity “Drill to Skin,” which is part of the expert model but excluded from the workflow model, can be added. It
adds enhancement to the workflow discovery algorithm. Detailed analysis and related enhancement is performed by my fellow researcher – Keyi Li, in this research project.

8. Related Work

Researchers in various fields have done related work for plan, activity, and goal recognition \[9\]. They have used probabilistic methods Hidden Markov Logic or Bayesian Logic for plan and goal recognition \[9\] which can be explored further to determine the plans and goals and build recommendation systems. While determining plan libraries and models automatically through activity discovery is an open problem, activity discovery algorithms have been introduced to challenge these problems \[9\].

Trace clustering based on local sequence alignment methods and k-means have been implemented to identify and cluster similar traces among all the activity traces and discover simpler process models \[5\]. Other process mining tools and frameworks have also been developed, like the open-source process mining framework ProM \[2\] (www.processmining.org), which has 100’s different plugins designed using process mining algorithms like Fuzzy Mining \[6\], Heuristics Mining \[11\], Petri net \[2\], etc. These plugins help find deviations and errors in processes, understand the medical procedures, reduce the “noise” (remove infrequent activities not relevant to the goal) and consider only the backbone behavior and generate the interpretable workflow models using the process logs \[2\][6][11].
9. Conclusion

In the first part of the thesis, we discussed how the goal realization framework helped optimize/repair the IV expert model, i.e., the IV Realization Algorithm that the experts had created using their theoretical knowledge and medical experience. We also discussed the framework developed to determine the ground truth, i.e., traces where the IV goal was met in real, which helped define the IV Realization Algorithm's accuracy after each experiment and analysis. Many experiments were performed with key findings, observations, and analysis discussed in each of them that led to the optimization of the IV Realization Algorithm, i.e., expert model after multiple revisions before finally arriving at a stable version. Also, we looked at an analysis that patients with age greater than 12 months will likely have IV placed in a single attempt. Importantly, we derived the plan libraries from the paths of the final IV Realization Algorithm that can be used to design recommendation systems. Lastly, in this part, we had helped enrich the dataset by correcting errors in it and generated statistical results that would allow experts to understand the common paths followed in practice to achieve the IV Goal.

In the second part of the thesis, we discussed the framework developed to generate the dataset from ground truth traces of the form that workflow discovery algorithms \[7\] and tools like DISCO can use to create interpretable workflow models and understand the medical processes. We also performed an analysis as to why the models generated from DISCO cannot be used for the interpretation of medical processes. Using ideas from previous work \[7\][10], we derived a linear workflow model using the workflow discovery algorithm \[7\] to understand the IV goal. We proved why it matches an optimized IV
realization algorithm by comparing the IV realization algorithm paths with the linear model.

This work's scope is extensive as other medical algorithms (expert models) like an IV realization algorithm can also be incorporated into this framework. And they can be optimized/repaired by performing similar experiments and analysis and generate plan libraries required to design recommendation systems.

10. References


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