Conformance Checking Challenge 2019: Analysis of Central Venous Catheter Installation with MEHRWERK ProcessMining

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Abstract. In the discipline of process mining, the area of conformance checking promises large contributions to process analysis and business intelligence. The 1st Conformance Checking Challenge 2019 (CCC19) offers an opportunity to apply innovative techniques onto real-world process data. We analyze a process of central venous catheter installation with ultrasound for which data were collected as part of the multidisciplinary research project 'Process-Oriented Medical Education (POME)' conducted by the School of Medicine and the School of Engineering of the Pontificia Universidad Catlica de Chile. As the data reflect the progress of students during a university course, we particularly analyze the two process perspectives of the instructor and the participating students. Taking the students' perspectives, we identify their mistakes to elaborate suggestions for improvement that contribute to their learning process. To support the instructor in his teaching, an aggregation of the overall process performance is derived to spot common mistakes in the group's performance. Mistakes are analyzed in the overall context but also in their subprocess's context to identify which part of the process seems to be difficult for students. The conformance checking results as well as the overall students' performance are captured in easy-to-understand dashboards to provide feedback tailored to each stakeholder.

Keywords: Conformance Checking · Process Mining · CCC2019 · ICPM2019 · MEHRWERK ProcessMining (MPM).

1 Introduction

The 1st Conformance Checking Challenge 2019 (CCC19) invites us to analyze a real medical training process regarding its conformance between the observed (event log) and expected behavior (model) [1]. Hereby, we are capable to present the contributions conformance checking techniques can already make to process analysis. Furthermore, we can demonstrate the conformance checking functionalities of our software MEHRWERK ProcessMining (MPM). To provide the process owners with interpretable and understandable conformance results we develop a report that covers a broad range of aspects for both stakeholders' perspectives (students and instructor). We aim for holistic analysis and usefulness for the purpose of a real-life process improvement.

1.1 Approach

To derive useful insights from the data we will follow the approach stated below:

1. *Data understanding:* through the MPM Process Discovery Algorithm we get a first impression on the process data, on sub-processes, on event duration and on process lead- and process idle times.
2. *Data pre-processing:* analyzing the time-related metrics, we detect outliers that will be corrected.
3. *Aligning the process instances* with the process model: with MPM Conformance Checking Algorithm we compute the alignment of event log and process model.
4. *Analysis:* to cover both the instructor's and students' perspectives, we construct dashboards on aggregated and detailed level that provide insights to the stakeholders. Using the dashboards as entry point, we dive deeper in the analysis with further visualizations.
5. *Interpreting results*:
   - To support the instructor in his teaching, common mistakes and similarities in the group's performance are spotted.
   - Taking the students' perspectives, we identify their peculiar mistakes to elaborate suggestions for improvement that contribute to their learning process.
   - The improvement during the course is analyzed to show the instructor and the students where additional training was helpful and where more additional training is recommendable.

The following paper is structured as follows: we briefly explain our understanding of conformance checking (section 1.2) and the tool MPM (section 2.1) that we are using in this paper. Then we comprehend the process and the data (see section 2.2) and preprocess them (section 2.3). In the last part one finds the actual process analysis (section 3) and a conclusion (section 4).

1.2 Preliminaries - Conformance Checking

In the discipline of process mining, according to van Dongen, "conformance checking is considered to be anything where observed behaviour needs to be related to already modelled behaviour" [2]. In general, the technique can be used to compute metrics that quantify the deviation between a log and a model. Alignment-based conformance checking employs alignments to depict the relation between a process sequence in an event log and a process sequence of a model [2]. For each real-life process variant, its' sequence of *activities* (nodes in a graph) and *moves* (transition from one activity to another, displayed as edge in a graph) is compared to the process model's sequences. Activities and moves are:

- either *synchronous*, referring to the fact that the observed behaviour corresponds directly to a possible behaviour in the model,
- or *in log*, which means that the observed behaviour can not be found in the model,
- or *in model* showing that this part of modelled behaviour has not occurred in the event log.

For better understandability we will refer to activity/move in log as *undesired activity/move*, to activity/move in model as *skipped activity/move* and to synchronous activity/move as *correct activity/move*. To clarify another concept we use later, we shortly define the following: by *lead time* we refer to the time from case start until case end, by *process step duration* we refer to the actual time consumed to fulfill an activity and by *idle time* we refer to the time passing by between the end of one and the start of the directly following activity, some call this transition time. Consequently, process step duration and idle time sum up to the lead time. As this paper's purpose is to apply conformance checking on real-life use cases, we will not go deeper in the explanations on conformance checking, the interested reader can find more detailed explanation on the topic and state-of-the-art algorithms in [3].

2 The Use-Case

2.1 Tool: MEHRWERK ProcessMining

MEHRWERK ProcessMining (MPM), deployed on the Qlik Sense® platform, is designed to offer comprehensive analytics to the process analyst. MPM combines self-service business intelligence, visual and associative analytics with the insights achieved by process mining algorithms, so that even non-experts find answers rapidly. Regarding conformance checking, MPM offers various functionalities: with the MPM ProcessModeler the user is able to define a happy path via drag and drop which will be displayed in the process visualization by coloring the happy path green and deviating behavior red. As a process model is delivered in this use-case, we will not apply this function, but if process models are not provided, it allows to rapidly investigate process deviations on-demand in an intuitive manner without scripting. Similarly easy to understand is the process query offered by MPM where the analyst creates a process sequence including wildcards that searches for matching process variants and displays them in the process analyzer (see figure 6). Hence, it is done with ease to find and investigate certain process behavior.

To achieve further insights on process deviations, MPM offers an alignment-based conformance checking approach that detects the closest *start to end sequence* in a model for each process variant. The algorithm evaluates activities and moves in model or log as well as synchronous activities or moves. With these information a fitness metric *Happy Path Fitness* indicating the most fitting model path for each real-life process variant is computed. This fitness metric is displayed as a percentage and supports the analyst in rapidly identifying highly deviating process variants, e.g. a process variant may have a fitness of 80% to its aligned happy path. Our fitness metric calculation can be adapted to specific process requirements. For the example process in this study, we decided that a correct activity set of a process is more important than the correct order of all activities. Therefore, skipping activities are more strongly sanctioned than deviating from the correct order.

2.2 Process Data

This 1st Conformance Checking Challenge provides data of a real-life Central Venous Catheter (CVC) installation training of medical students [4]. The CVC is used for delivering liquids, fluids or medicines to patients. The should-be process of the procedure can be found in the BPMN model shown in figure 1.

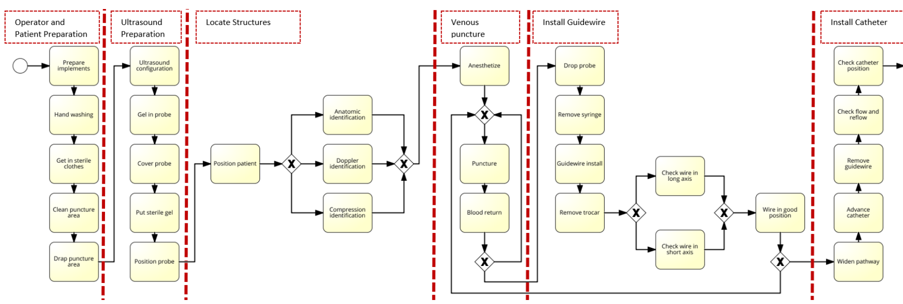
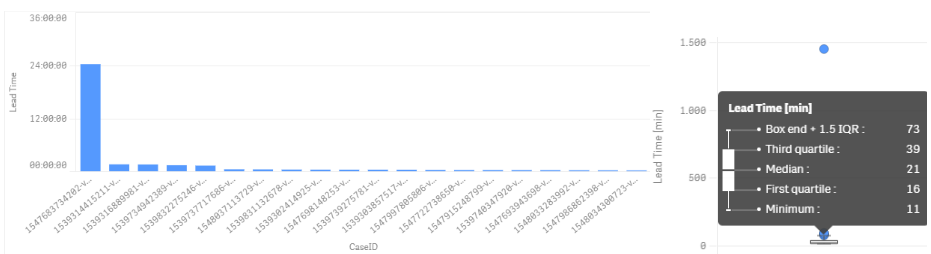


Fig. 1: The BPMN model of Central Venous Catheter (CVC) installation

The following presents the verbal description of the CVC installation according to [4]: First, the implements are prepared, the hands are washed, and the doctor gets in sterile clothes. The doctor cleans the puncture area and draps the zone. Then he configures the ultrasound and puts gel in the probe. Then, he covers the probe and puts the sterile gel. The doctor positions the probe and positions the patient. The vein is identified using anatomic identification, doppler identification, or compression identification. The patient is anesthetized and punctured. The blood return is checked. If the blood return is not correct, the doctor goes back to the puncture step. If the blood return is correct, the probe is dropped, and the syringe is removed. The guidewire is installed, and the trocar removed. Then the wire is checked using a check of the wire in the long axis, or the short axis. Then, the doctor checks if the wire is in good position. If the wire is not in the good position, the doctor goes back to the puncture step. If the wire is in the good position, the pathway is widened, the catheter is advanced, and the guidewire is removed. Finally, the doctor verifies the flow and the reflow, and the catheter position is checked. The process is divided in six sub-processes, as can be seen in figure 1: *operator and patient preparation*, *ultrasound preparation*, *locate structures*, *venous puncture*, *install guidewire* and *install catheter*. To train students, they are firstly taught by their instructors, then they take a first preliminary test (pre-round) after which they can practice on their own. A second final post assessment (post-round) is taken to show if they have acquired the skills to install a CVC during the course. [1]

Ten students have been filmed during the pre- and post-test, leading to 20 different process instances. The event log provided was created by tagging the activities in the videos and then deriving their timestamps, hence, noise is present in the data set. The event log consists of 697 events and, after performing process discovery to get first insights in the process data, we detect 20 different process variants for the 20 cases.

2.3 Data Pre-Processing



(a) Cases by lead time in hours before preprocessing.

(b) Boxplot of lead time distribution.

Fig. 2: Outlier detection by lead time.

Visualizing the data and the cases' lead time presented five outliers: in figure 2a we ordered the cases by lead time and found five cases with very high values. These are statistically signifcant outliers because their lead times are above the upper whisker in the boxplot shown in figure 2b. We then investigated the log in detail and found the specific errors. These are listed in table 1. For case 1547683734202-video_1.c_CVC the date of the activity timestamps suddenly changed from 16.01. to 17.01. while the hour seems correct. For the other four cases in table 1 the timestamps were shifted by one hour for the rest of the process. The extra hour occurred always between two events, increasing the idle time between them to an unreasonable duration. We decided to correct the data, otherwise we would have lost 25% of the cases for analysis. We also decided against interpolating the times, because the shift by 1 day or 1 hour seemed reasonable to us, as the events were tagged manually in the videos. We assume that this is part of the noise mentioned in the challenge's description and felt free to alter the timestamps of these five cases. To correct the data we manually shifted the time back to the hour (or the day) of the previous events.

Table 1: Detected outliers and their manual correction

Case ID	Activity	End timestamp	Succeding Activity	Succeding start timestamp	Correction
1547683734202-video_1.c_CVC	Position probe	1/16/2019 1:09:40	Ultrasound configuration	1/17/2019 1:09:48	Date set back to 16th Jan.
1539314415211-video_2.1_CVC	Drop probe	10/12/2018 2:16:41	Puncture	10/12/2018 3:17:00	Hour set back to 2 for following events
1539832275246-video_4.8_CVC	Clean puncture area	10/18/2018 2:02:52	Drap puncture area	10/18/2018 3:02:57	Hour set back to 2...
1539316889981-video_3.1_CVC	Widen pathway	10/12/2018 3:31:22	Advance catheter	10/12/2018 4:31:23	Hour set back to 3...
1539734942389-video_3.2_CVC	Prepare implements	10/16/2018 23:15:20	Position probe	10/17/2018 0:15:28	Hour set back to 23...

3 Results

We were asked to analyze the process from different stakeholders' perspectives. Hence, we divided this chapter into two parts. At first, we will present the process insights on an aggregated level which corresponds to the instructor's perspective. Then we will focus on one specific student who stood out from the others by being the only one increasing instead of reducing his lead time while at the same time improving strongly on his happy path fitness.

3.1 Instructor's Perspective

The course's instructor would be interested in detecting typical mistakes of his students to focus the teaching process on the most critical process stages. To give a concise entry point for the analysis from the instructor's point of view we created a dashboard for him (see figure 3 and 9). We consider the lead time and the correct execution of the process as crucial to successful CVC installation. Therefore, the focus of the dashboard is on skipped activities, undesired moves, reworked activities and the process times by stage. The KPIs at the top of the dashboard capture the students performance and improvement from pre to post: lead-, process- and idle time are represented as well as the happy path fitness and the number of undesired/skipped activities/moves calculated for the pre- and the post-round. At the left side, the processes are shown by the given round with the process deviations colored in red. For a specific explanation of the process visualization please see figure 14. The other four diagrams on the dashboard will be explained and analyzed in the following report. The dashboard gives a short verbal summary at the bottom to present the most significant behavior and hint on stages that need to be explained better.

To give a report for the instructor we will, firstly, generate general insights in common mistakes and probable reasons for high process lead times in the pre-round. Then, we will derive recommendations for the instructor on where to focus his teaching to prepare the students best for their final test. Having the post-round process data, we will evaluate the improvements the students achieved in the post-round and, finally, we give a short conclusion what can be learned for the next course from the results.

Process diagnosis in the pre-round For the pre-round we can state that the students have deviated strongly from the process model: there are a lot of red lines (marking undesired moves) in the process visualization of figure 3, showing clearly the large number of undesired moves. Having this first impression we will start analyzing the process conformance and then use the achieved insights to further analyze process times and reworked activities.

Process conformance: A large part of the red lines occurred in the stages *operator and patient preparation*, *ultrasound configuration* and *locate structures*. As undesired moves are caused by either skipped or undesired activities or wrong ordering of the process, we will at first focus the analysis on this topic. We see in *Occurrence and typology of activities* in figure 3, the activities that often have been skipped in the pre-round were *wire in good position* and *position patient*. It might be, as these are rather invisible activities in a process, that they haven't been tagged correctly in the video. But, if these missing activities are not caused by an event log generation error, the students should be made aware not to forget these steps again. Furthermore, the instructor should notice that three of his students have not *checked the catheter position* and two of them have forgotten to *anesthetize* their patient. These are severe errors, that would cause large damage in real CVC installations. Additionally, two students have not *checked the wire*, two did not *position their probe* and one forgot to *check the flow and reflow*. It seems, for these large list of skipped steps, as if some students do not memorize the single process steps of the stages *ultrasound configuration*, *install guidewire* or *install catheter* well and should work on these specific process stages.

The top ten undesired moves performed by the students in the pre-round are, all but one, part of the first three process stages (see the bar chart *Occurrence and typology of moves* in figure 3). Only the move *remove trocar - widen pathway* occurred in a later stage. We conclude from this that the students did not take the preparation steps very seriously and/or miss a lot of routine in these basic process steps. With an average of 20 undesired moves and two skipped activities the students often deviated from the process sequence. The top undesired activities are all part of the *vein identification* or the *checking wire step* (see figure 4a). These probably occur because the students did not feel confident enough to trust on one method.

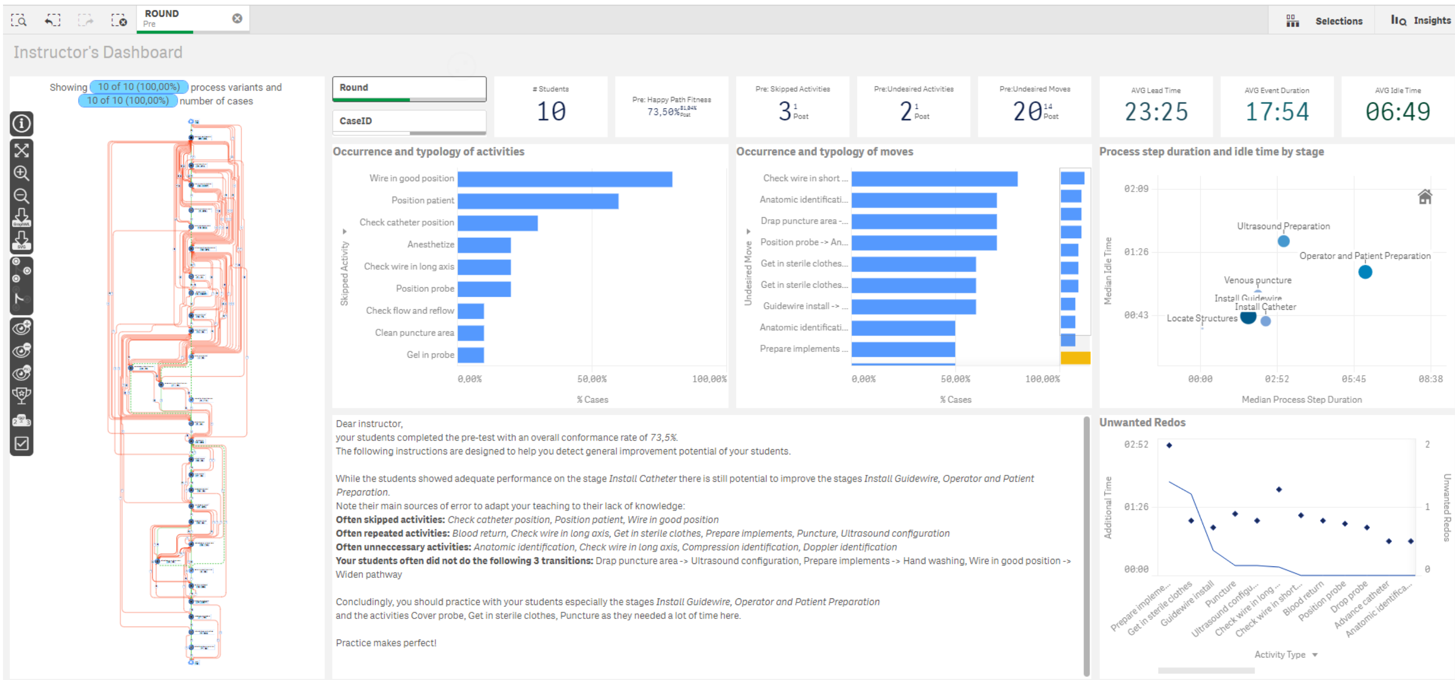
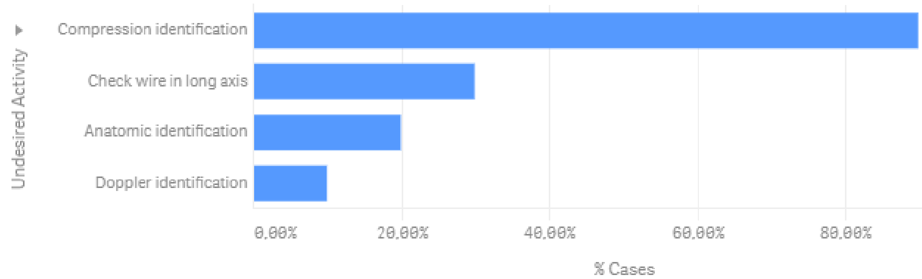
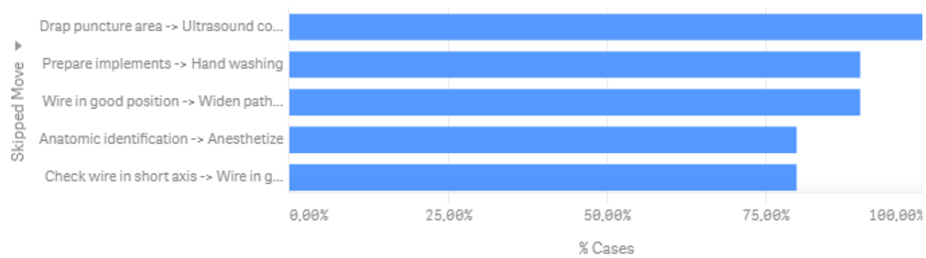


Fig. 3: This dashboard is generated for the instructor to give an overview on the students' performance in the pre-round.



(a) Undesired (redundant) activities performed by the students.



(b) Skipped moves (changed activity order) performed by the students.

Fig. 4: Deviating behaviour detected in the pre-round ordered by occurrence.

For their lack of routine, the students often changed the ordering of activities. Hence, in figure 4b we analyzed the top five of these changed activity sequences: no student started the *ultrasound configuration* after *draping the puncture area*. Just one understood to *wash his hands* after *preparing the implements* and one went directly from knowing the *wire's good position* to *widening the pathway*. Eight students did neither realize the *anesthetization* after *the anatomic identification* nor did eight students reach the state *wire in good position directly* from *checking the short axis* – probably they double checked in both situations.

By looking at figure 3, we know that one third of the students did not finish their process by *checking the catheter position*. It is interesting for the instructor to understand, if these students have not *installed the catheter* successfully at all or how they completed the process otherwise. By filtering on cases that do not stop with the desired activity, we infer that one student finished by *removing the guidewire*, one by *checking the flow and reflow*, and one by *advancing the catheter*. The first student *installed the catheter* after some complications but did not make sure that the catheter was positioned well. The second student forgot to *check the flow and reflow*. The third student who stopped by *advancing the catheter* was probably not successful as he repeated the process of *catheter installation* and then broke up before *removing the guidewire*. Thus, we conclude as before: the instructor should secure that his students pay more attention to checking operations.

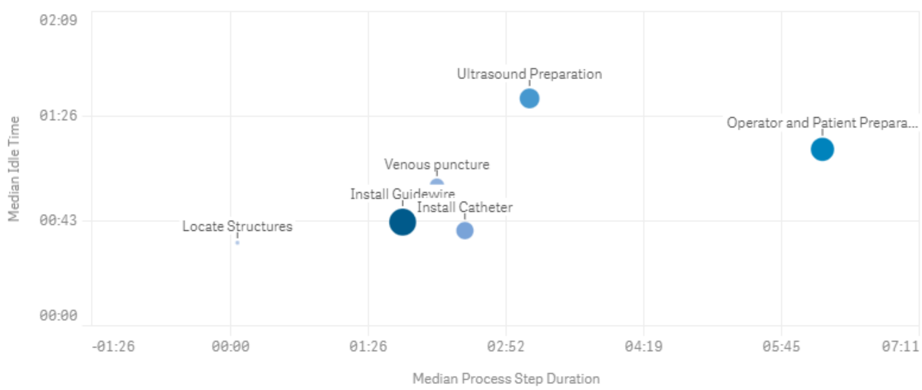


Fig. 5: Process stages by idle time and event duration (in minutes).
Size and color depend on the number of activities belonging to the stage. Darker and larger equals more activities.

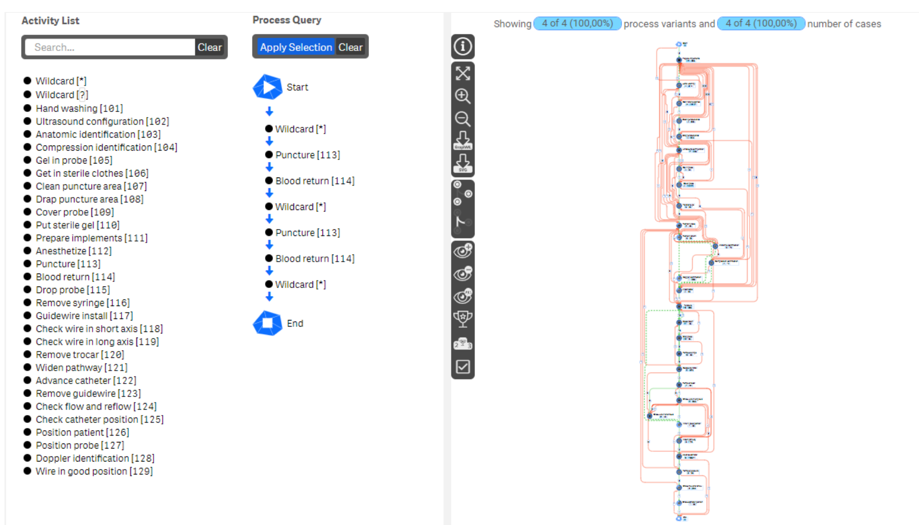
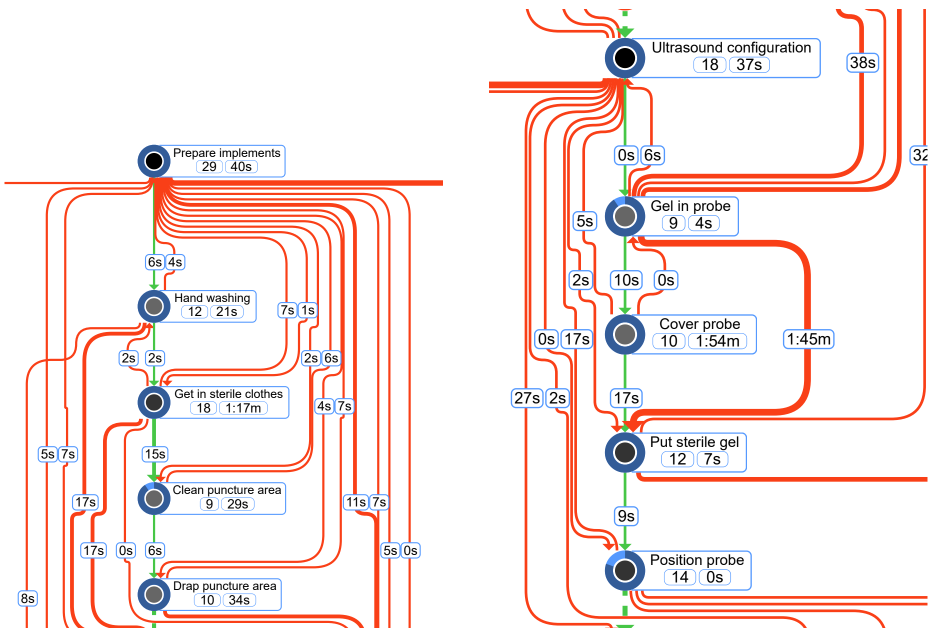


Fig. 6: MPM QueryBuilder - repetition of *puncture* to *blood return*.
The MPM query function allows process queries via drag and drop. To show the instructor how many students repeated the sequence *puncture* to *blood return*, the left query filters the visualization on the right. Four students in the pre-round were detected.

Process time and rework analysis: According to figure 5 the most time consuming stage regarding the process step duration is *Operator and patient preparation* with 6:11 minutes. The idle time is also high with 1:13 minutes. These rather basic process steps consume an unconvenient amount of time as can be clearly seen in figure 7a. The stage with the highest idle time of 2:03 minutes was *ultrasound preparation*, furthermore, the sum of event durations was pretty high with 3:17 minutes. The high overall event duration was mainly caused due to the average of 1:54 minutes needed to complete the event *cover probe* while the large idle time is based on the move from *cover probe to put in sterile gel*. This can be seen in the process visualization in figure 7b. Also, interesting in figure 7b is the high number of occurence of the activity *ultrasound configuration*. Ten students performed this activity 18 times, so a further analysis might be interesting: in figure 8a we see that all, except for three students reworked the *ultrasound configuration* at least one time which causes unneccessary extra time. The instructor might be interested in other repetitions as well, so we created figure 8b that demonstrates all activity repetitions occurring in the pre-round. We notice an overall high repetition for the activities *prepare implements* and *get in sterile clothes*. How many students have repeated these and other activities can be seen in table 2. To present how the instructor can rapidly find interesting process sequences, we analyzed processes carrying out a multiple puncture sequence with the MPM QueryBuilder. As a result we can see in figure 6 that four students in the pre-round had to re-do the *venous puncture*.

Table 2: Number of students repeating activities in round pre and post

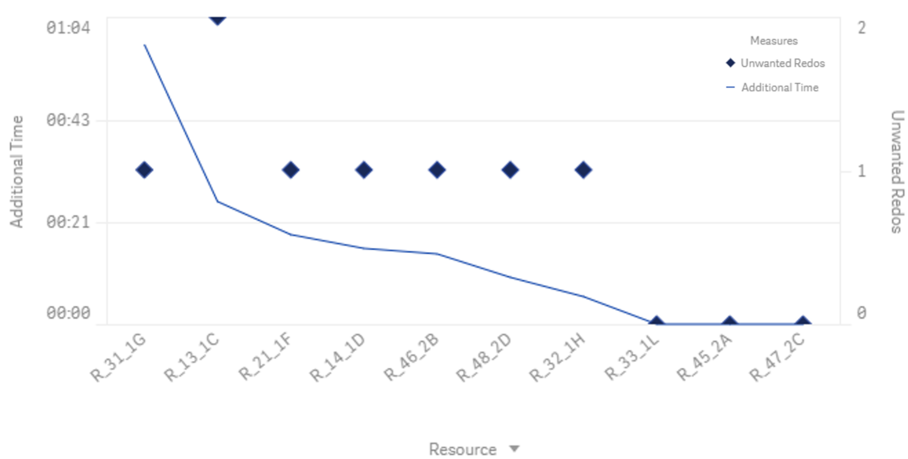
Stage	Repeated Activity	#Cases (pre)	#Cases (post)
Operator and patient prep	Get in sterile clothes	8	9
Operator and patient prep	Prepare implements	8	10
Ultrasound prep	Ultrasound configuration	7	5
Install guidewire	Guidewire install	6	1
Venous puncture	Blood return	4	1
Install guidewire	Drop probe	5	1
Venous puncture	Puncture	5	1
Install guidewire	Remove syringe	5	1
Install catheter	Advance catheter	4	1
Install guidewire	Check wire in long axis	4	3
Ultrasound prep	Position probe	4	1
Locate structures	Anatomic identification	3	1
Install guidewire	Check wire in short axis	3	2
Install guidewire	Remove trocar	3	1
Operator and patient prep	Hand washing	2	-
Ultrasound prep	Put sterile gel	2	-
Install catheter	Widen pathway	2	-
Venous puncture	Anesthetize	1	-
Locate structures	Compression identification	1	1
Install catheter	Remove guidewire	1	-



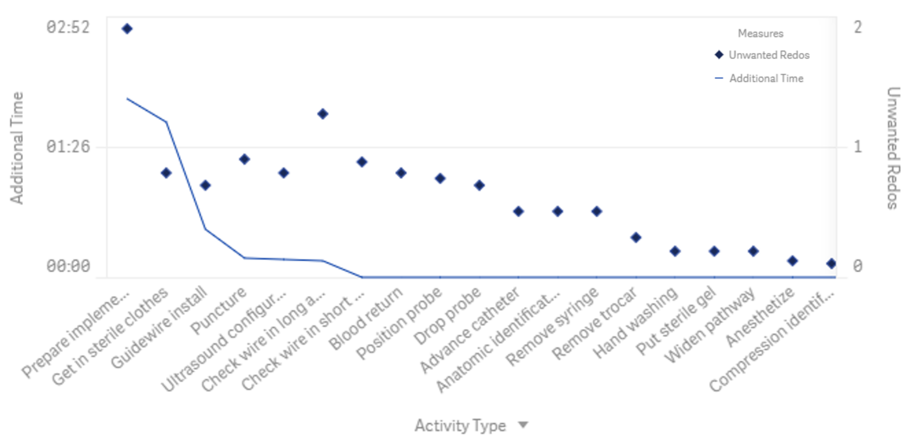
(a) Stage *operator and patient preparation.*

(b) Stage *ultrasound configuration.*

Fig. 7: The graphs show isolated stages of the pre-round process. The first number in the nodes is the frequency, while the second is the average process step duration. The durations at the edges represent the idle times.



(a) Repetitions of *ultrasound configuration* and added process duration per student.



(b) Average repetitions for each activity and average added process duration.

Fig. 8: Repetitions and their additional process step duration.

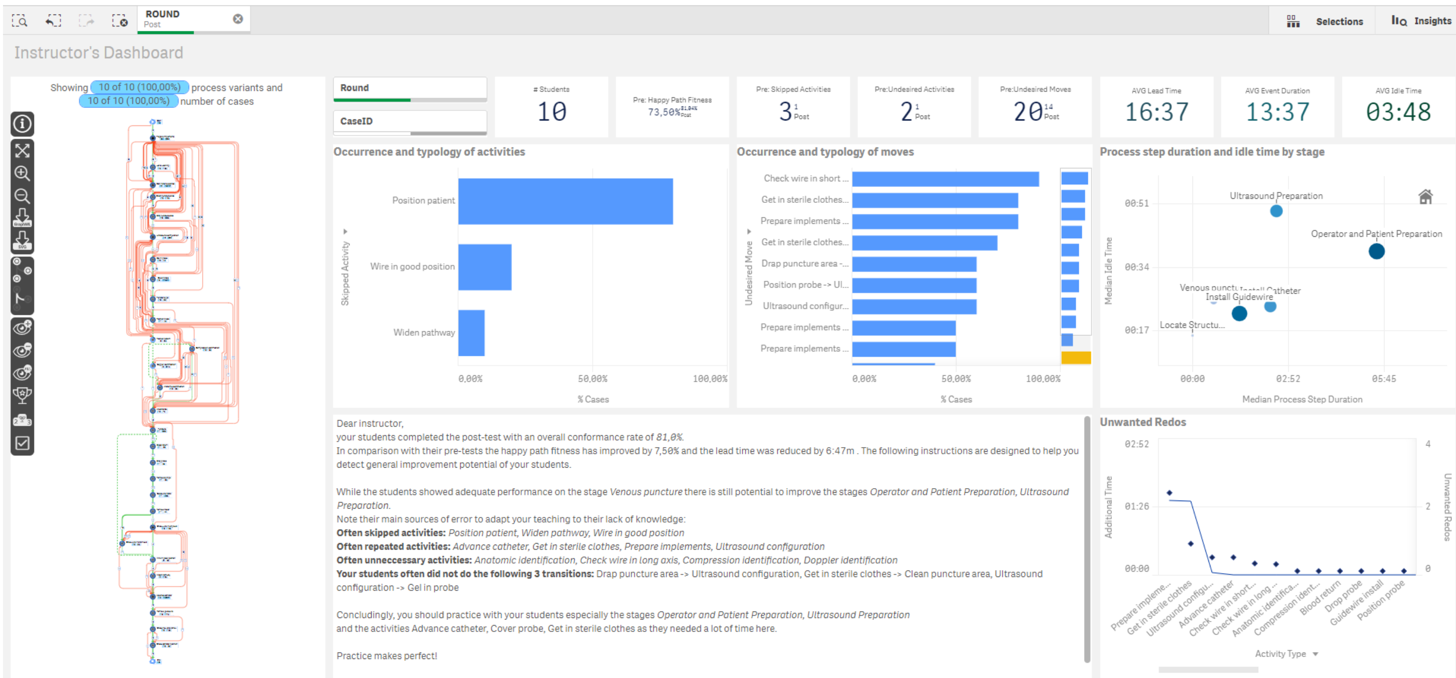


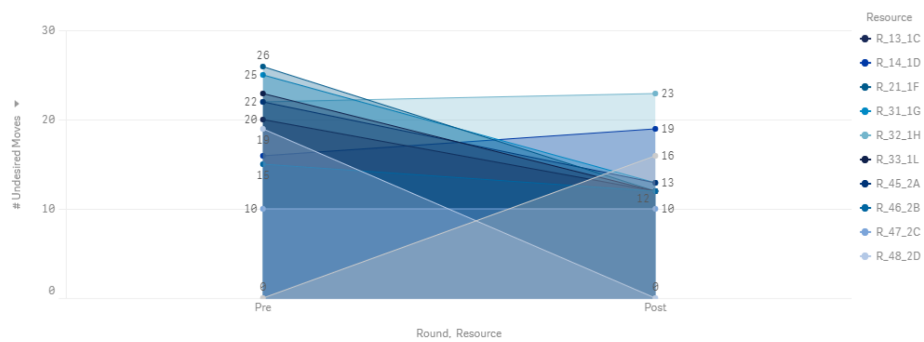
Fig. 9: The instructor's dashboard for the post-round.

Recommendations for the instructor: As the students completed the pre-round with an average of 73.5% there is large potential for improving their performance. Especially in the stages *operator and patient preparation* and *install guidewire* the students deviated highly from the process model. Their main errors were skipping the activities *wire in good position*, *position patient* and *check catheter position*. Additionally, they did a lot of rework in the activities *prepare implements*, *get in sterile clothes*, *blood return*, and *check wire in long axis*. The latter might be caused due to not trusting in their own skills or in only one checking method. As critical, we perceive that 40% of the students did not hit the vein in the first try and needed to return to *venous puncture*. Furthermore, students seldomly went from *draping the puncture area* directly to *configuring the ultrasound*. When the wire was found to be in a good position the students did not conclude with *widen pathway* but other process steps. Also, *hand washing* was rarely performed after *preparing the implements*. Summing up, some students did not well memorize the single process steps of the stages *ultrasound configuration*, *install guidewire* or *install catheter* and should be trained on these specific process stages. Furthermore, they miss routine in the basic process steps of the preparation phase. As practice makes perfect the instructor probably could help them best by re-explaining the overall process, putting emphasis on the importance of doing the required checks and by motivating them to practice on their own to gain more confidence.

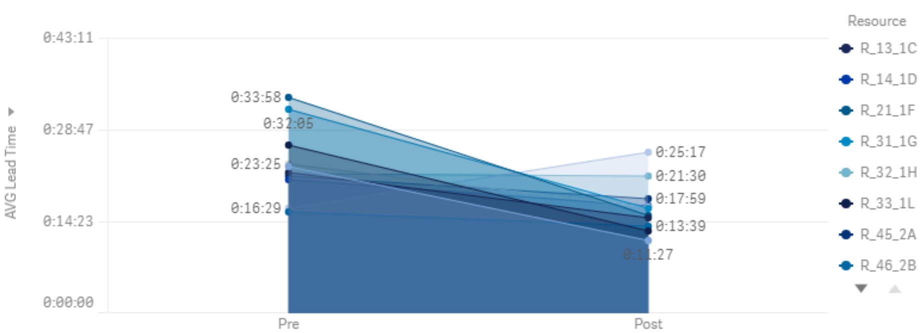
General improvements achieved in post-round The students improved their average happy path fitness by 7.5%. This time instead of the stage *installing guidewire*, *ultrasound preparation* was more difficult. Figure 10a demonstrates the reduced number of undesired moves for all but three participants. Similar analysis can be made for skipped activities or undesired activities leading to the result that the skipped activities dropped for each student (see also *unwanted redos* in figure 9) and the undesired activities increased for only two of them. The skipped activities in the post-round have been *position patient* (eight students), *widen pathway* (one student) and *wire in good position* (two students). The *check of the catheter's position* that was missing in the pre-round has not been skipped again. This can be seen in figure 9.

The most often repeated activities are again *get in sterile clothes*, and *prepare implements*. New to the list is *ultrasound configuration*. The number of cases with repeating activities in general dropped strongly, as can be seen in table 2. Unnecessarily performed process steps did not change from pre- to post-round. This might be excused by the students being more confident doing double-checks with different methods to get a good result on *puncturing the vein*. Indeed, good results were achieved because every student finished his process successfully, only one did not finish with *check catheter position* because he switched the order of the last two activities.

Regarding the process times figure 10b shows that the case lead time dropped for all but one student. The average lead time dropped by 6:47 minutes. A good overview on the statements we made is given in figure 11. It is noticeable that only two students were able to perform their process without skipping an activity (as skipping activities in this kind of delicate process is dangerous, we colored entries red for every student who skipped at least one). Comparing the bubble charts of the pre- and post-dashboard in figure 3 and 9, one will notice, that the idle time has reduced for all stages. While the process step duration for *ultrasound preparation* and *operator and patient preparation* has nearly not changed, the other stages, especially *venous puncture*, became faster. The student, R_48_2D who did not improve his lead time from pre to post, has improved his process conformance dramatically, so he might be a good example for more detailed analysis. Therefore, in the next section *Student's Perspective* we will describe the insights R_48_2D can get from the conformance checking.



(a) Evolution of number of process steps.



(b) Lead time evolution in hours.

Fig. 10: Process evolution from pre to post for each student for different metrics.

All in all, the instructor was able to help his students improving. The core parts of the process, namely the stages *venous puncture*, *installing guidewire* and *installing catheter* have improved highly. Nevertheless, the preparation stages could still be improved as those are quite red in the process visualization shown in figure 9. In fact, by utilizing the MPM QueryBuilder mentioned in chapter 2.1

we searched for students who begun the process according to the process model and found only one single student in the post-round. This result is displayed in figure 12. Even if this part of the process is not the most critical, some routine might speed up the process and boost the student's self confidence.

Student	Fitness Pre	Fitness Post	+/- Fitness	Lead Time Pre	Lead Time Post	+/- Lead Time	Skipped Activities Pre	Skipped Activities Post	+/- Skipped Activities
Totals	**73,5%**	**81,0%**	**7,5%**	**240:12**	**168:42**	**-29,8%**	**26**	**11**	**-57,7%**
R_13_1C	71,3%	80,5%	9,2%	23:38	14:39	-38,0%	3	2	-33,3%
R_14_1D	78,0%	76,9%	-1,1%	23:53	18:02	-24,5%	2	1	-50,0%
R_21_1F	77,4%	82,0%	4,6%	33:39	16:04	-52,3%	2	1	-50,0%
R_31_1G	72,3%	82,1%	9,9%	31:46	16:12	-49,0%	2	1	-50,0%
R_32_1H	73,5%	70,1%	-3,5%	22:42	22:42	-0,0%	2	2	0,0%
R_33_1L	64,7%	86,7%	22,1%	27:27	12:45	-53,6%	4	0	-100,0%
R_45_2A	69,3%	82,3%	13,0%	21:56	19:06	-12,9%	4	1	-75,0%
R_46_2B	79,2%	83,6%	4,5%	16:17	13:22	-17,9%	1	1	0,0%
R_47_2C	79,0%	82,3%	3,3%	22:47	10:58	-51,9%	3	2	-33,3%
R_48_2D	70,5%	84,5%	14,0%	16:07	24:52	54,3%	3	0	-100,0%

Fig. 11: Summary on the performance improvement from pre- to post-round.

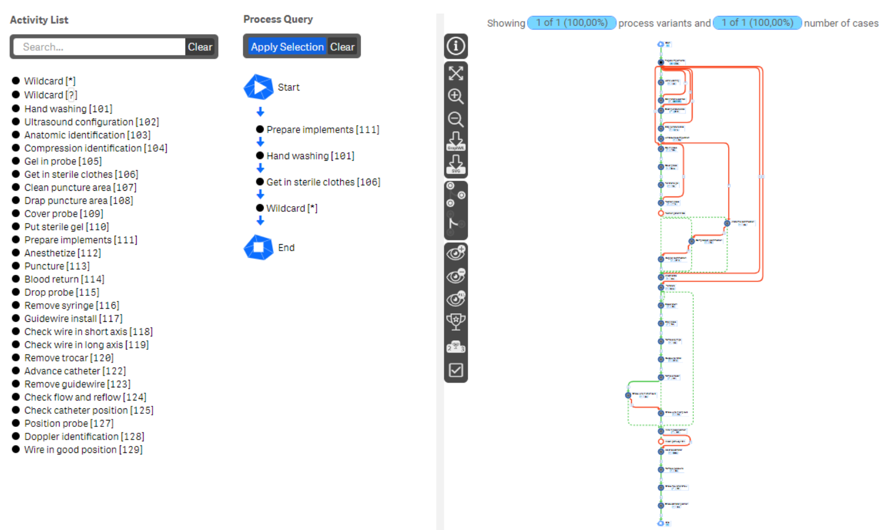


Fig. 12: MPM QueryBuilder result - students' conformance with the start sequence of the CVC installation process.

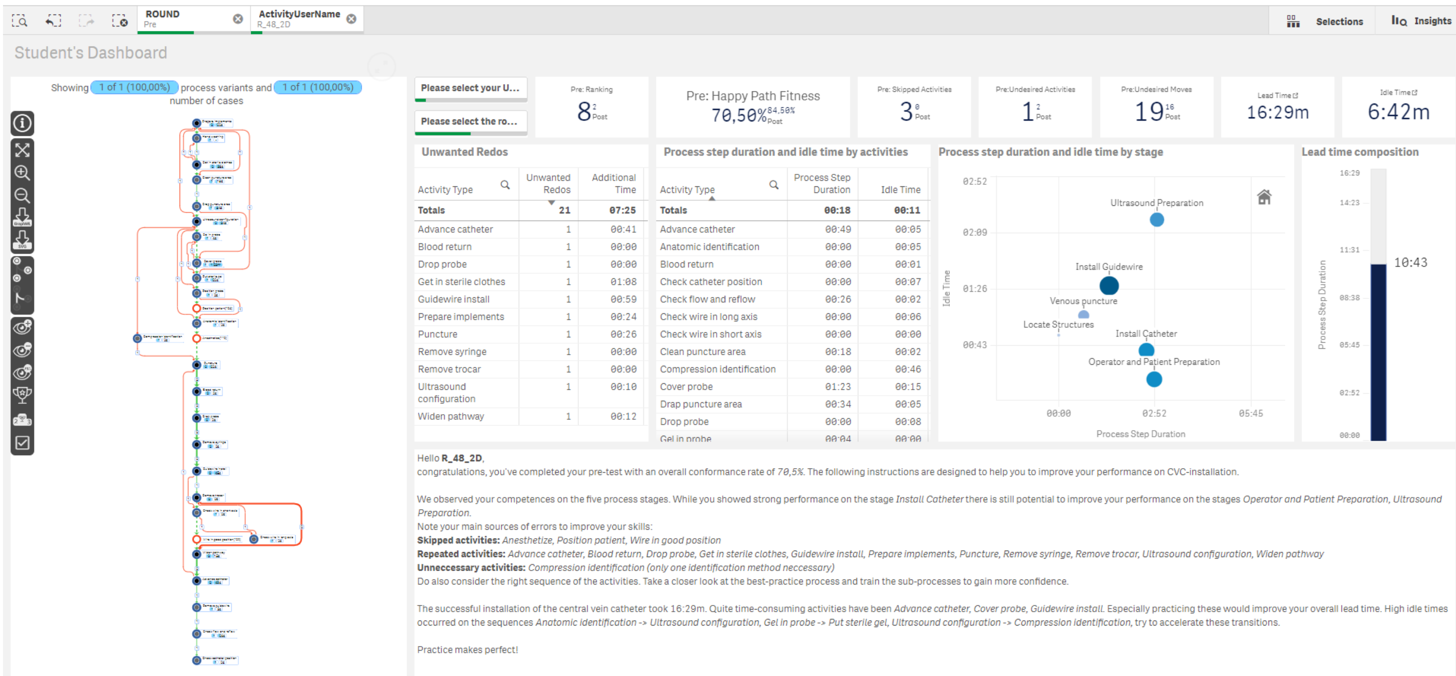


Fig. 13: The student R_48_2D's dashboard for the pre-round.

3.2 Student's perspective

As a student, one would be interested in discovering errors and specific improvement potentials. Therefore, we designed a dashboard (see figure 13 and 15) that serves as starting point for deeper analysis by giving an overview on missing activities, undesired moves or activities, as well as the re-dos and the extra time caused by them. For each activity and stage, the process step duration and the idle time is presented which allows the student to rapidly find out where he lost most time in the process. At the top of the dashboard are some KPIs to capture the student's performance and improvement from pre to post: a ranking shows the student's position within the course; lead-, process- and idle time are represented as well as the happy path fitness and the number of undesired/skipped activities/moves is calculated for the pre- and the post-round. A message is derived for the student where errors and hints of improvement are listed. At the left, the process performed by the student is shown and process deviations are marked clearly. For a specific explanation of the process visualization please see figure 14.

The report we will give in the following is created for student R_48_2D's performance and can be seen as an example for every other student. The analysis will be divided into two parts: the diagnosis on detailed process deviations in the pre-round including improvement proposals and the diagnosis of actually achieved improvements in the post-round.

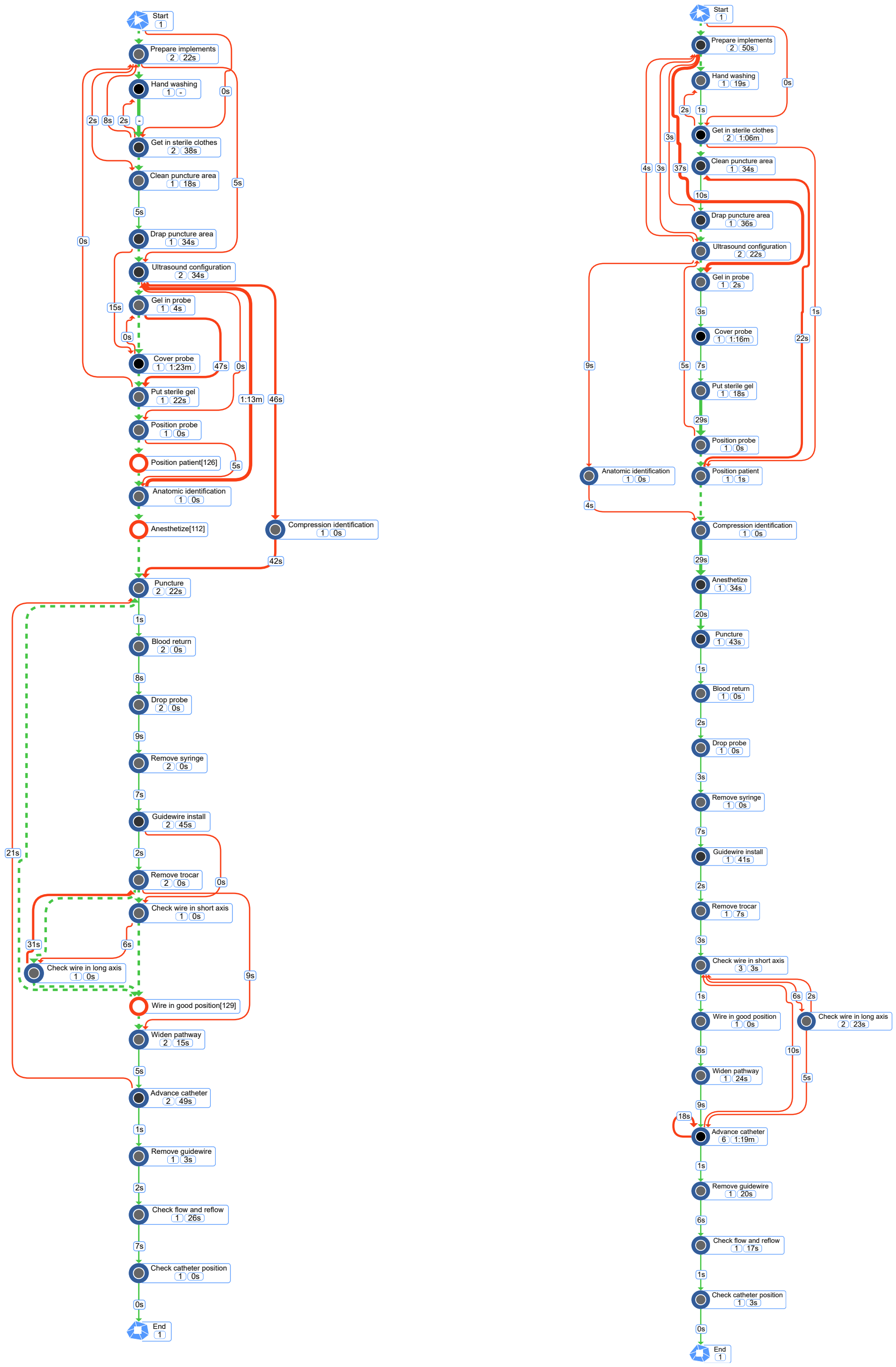
Diagnosis of detailed process deviation in the pre-round In the pre-round student R_48_2D was eighth of his course due to his process path fitness of 70.5% (see figure 13). It is noticeable that he skipped three activities, quite a high number in a delicate process as the CVC installation. The bubble chart *Process step duration and idle time by stage* of figure 13 shows that the student spent a lot of time especially on the *ultrasound preparation* with a high idle time of 2:20 minutes and a high process step duration of 2:57 minutes. To analyze the deviations and process times we will have a closer look on the process visualization.

Deviation from process model and lead time analysis: The process map in figure 14a shows that the student R_48_2D deviates strongly from the process model. Only two moves in the first part of the process from *perpare implements* to *puncture* can be characterized as correct which is partly caused by the high number of rework the student did. For example, the *preparation of implements* and *putting sterile clothes on* is done twice (see table *unwanted re-dos* in figure 13 and the event counter of figure 14a). Comparing to the process model, the student started the CVC installation wrong by not beginning with the *preparation of implements* but by *putting repeatedly sterile clothes on* and *washing hands*. Additional to these less severe issues, the student committed two mayor errors in this first part of the process by not *positioning his patient* and not *anesthetizing* him. This is shown by the two skipped activities (redly marked) in figure 14a. Likewise, demonstrated by the process graph, is the strong deviation of the stages *ultrasound configuration* and *locate structures*. This can be seen easily in the high number of red lines, namely undesired moves. For example, the *ultrasound configuration* should happen before *covering the probe* and *putting gel* in it, but the student changed the ordering of events, which might be the reason for *ultrasound configuration* being repeated after doing *anatomic identification*. We suppose that mixing up the process order led to the student needing 47 seconds when transitioning from the event *gel in probe* to *putting the sterile gel* which is an undesired move. He spent even more time on returning from the *anatomic identification of the vein* to the second *ultrasound configuration* which is, as well, an undesired move. It cost him 1:13 minutes to start this activity again, which might be a sign of uncertainty.

As can be seen in figure 14a, the part of the process from *puncturing the vein* until the *guidewire install* was done according to the process model and unproblematic with respect to process and idle times. Then, the student made an error moving from *guidewire install* directly to *remove trocar*, without doing *checks of the wire*. As he did not confirm the wire's good position, he commits the next error by directly *widening the pathway* and *advancing the catheter*, whereby he realized that the wire's position was bad and he had to turn back to *puncture the vein* again. Circling back in the process took the student an extra 21 seconds. In the next try, he did *check the wires position* twice, but he did this deviating from the process model by doing it before *removing the trocar*. This undesired move took him 31 seconds which is double compared to the idle time of 16 seconds experts showed according to the paper [5][5]. The second try of *advancing the catheter* was successful and the student followed the process model correctly until the process' end. It has to be stated that *advancing the catheter* took student R_48_2D in average 49 seconds which is 26 seconds longer than the time consumed by experts [5].

Recommendations for improvement: Summarizing the insights we derived by the conformance checking, student R_48_2D should definitely practice the *ultrasound configuration*. He could also work on his preparation routine, to not loose e.g. valuable time on such basic process steps. All in all, the student seemed very insecure in the pre-round, as he forgot most important things like *anesthetizing the patient* or *checking the wires position*. As it is most important for doctors to work under extremely high pressure, the student should memorize the whole process better. Thus, he would not need to overthink each step and would perform the CVC installation more routinely.

[5] Experts event durations and idle times can be found in paper [5]'s figure 4.



(a) Round PRE.

(b) Round POST.

Fig. 14: Process visualization of pre- and post-round for student R_48_2D. Centered activities and their order represent the aligned happy path. Activities outside this centered path are undesired. Green lines represent correct moves. *Dotted green lines* show skipped moves. Red activities are skipped and red lines depict undesired moves. The activity labels have two metrics, the number of occurrences and the event duration. Edges are labeled with their idle time.

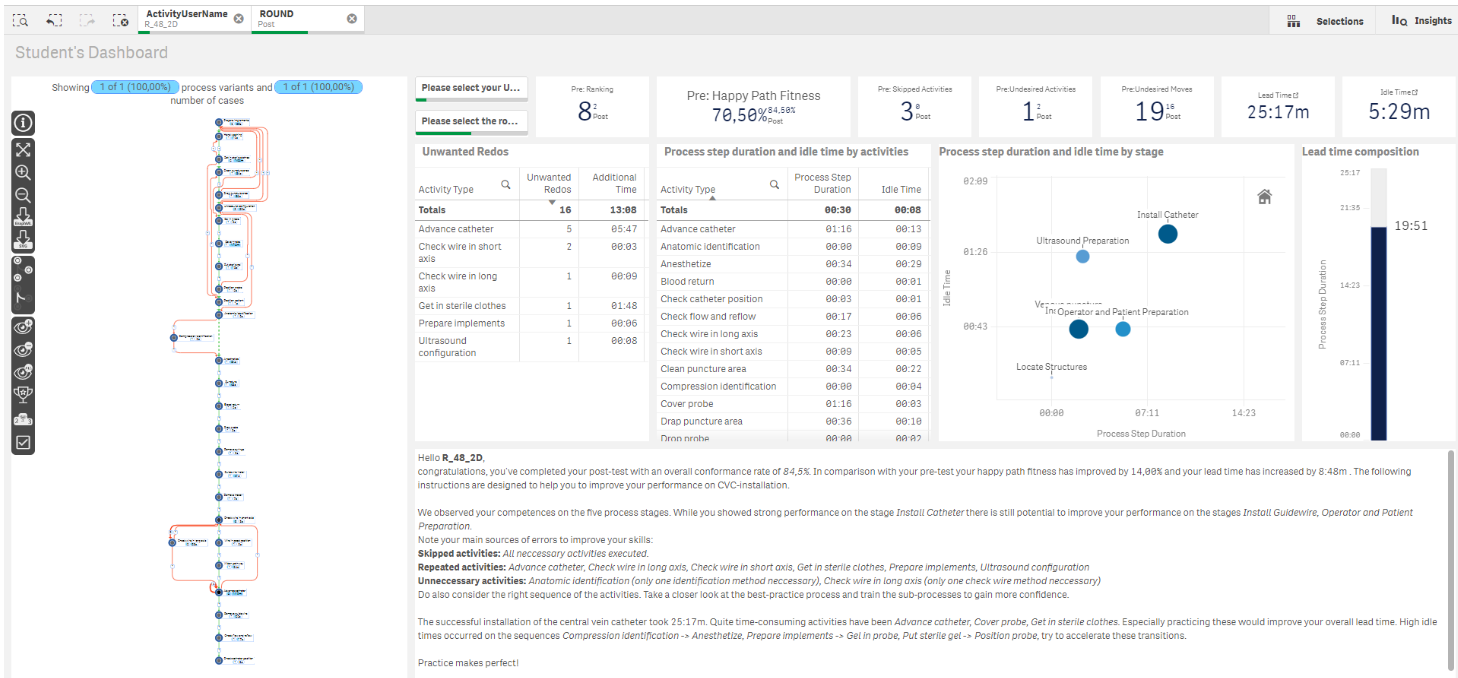


Fig. 15: This dashboard is the summary for the post-round of student R_48_2D.

Detailed improvements achieved in post-round The post-round process can be seen in figure 14b. The student R_48_2D is still unsure about a good process order of activities in the stage *operator preparation*. For example, he still didn't start with *prepare implements* and he was even slower in *putting sterile clothes* on than in the pre-round (figure 14b). *Cleaning and draping the puncture area* also cost him 21 seconds more than in the pre-round. Probably, the student was pretty nervous on his final test. We deduct this from the fact that in the pre-round he performed better due to less pressure.

This time, the stage of *ultrasound preparation* is done with less process deviations and 40 seconds less idle time (comparing the bubble charts in figure 13 and 15). The sequence *prepare impelements - ultrasound configuration - prepare implements - gel in probe* might be noise due to the manual tagging. If it was, this process sequence without *prepare implements* would be okay. The ultrasound configuration again is done twice, we suppose, the student double checked his tool to avoid errors. He should learn to trust his skills so he needs to do it only once. Nevertheless, he configured the ultrasound in average 12 seconds faster than in the pre-round (see event duration in figure 14b). This time he has not forgotten to *position his patient* but he did it before the *ultrasound configuration* which is not optimal because this way the patient has the chance to move and change his position right before the vene's position is checked and the anasthetizing is started. Furthermore, the student showed a large improvement by not forgetting to *anesthetize* the patient. The student was still doing extra work by identifying the vene's position twice. It seems as if the student was still not confident about his skills to identify the vene with one method.

The stage *installing guidewire* was done only once in the post-round and with less idle time than before, so here we see an improvement. Contrarily, the process step duration was higher (bubble chart in figure 15). Regarding the process deviation, the sub-process is conformant to the process model until the student reached the point of *checking the wire's position* (see figure 14b). Here, he did three checks (short, long, short axis). In the stage *installing catheter* the student *advances the catheter* four times, which accumulates to 5:20 minutes, a pretty long time and significantly worse than in his pre-round. Then he *checked the wire in long and short axis* again to get back to *advancing the catheter* two times more which costs him another 2:20 minutes. The high processing time of *advance catheter* is the reason why in figure 15 the stage *install catheter* is positioned at the very right in the bubble chart. Due to this decline in performance under the more stressful situation of having a final test, we state that, likewise, to *identifying the vein*, the actual process of *installing the catheter* is highly stressful for the student as he needs to reassure himself several times.

This example shows clearly that being close to the process model, as the student is with his 84.5% of happy path fitness, does not automatically imply that he is now capable of performing well on a real-life CVC installation. Imagining the scenario, that the vein was collapsed, for example, due to great loss of blood pressure caused by injuries, would the student have reacted fast and confident enough to install the catheter and save the patient? In our opinion, the most critical parts of the installation of a central vein catheter are *identifying the vein, puncturing it* correctly and *installing the catheter* smoothly. So, we would recommend the student to practice the mentioned crucial steps as often as possible, preferably in situations with increased psychological pressure.

4 Conclusion

The 1st Conformance Checking Challenge 2019 (CCC19) gave us the opportunity to apply innovative techniques onto real-world process data. We analyzed a process of central venous catheter installation with ultrasound, carried out two times by ten students. To give process-oriented feedback to the stakeholders, we created dashboards and further analytics using MEHRWERK ProcessMining that focus on process deviations regarding changed ordering of activities, extra work or skipped process steps. Furthermore, we analyzed rework and processing times, as velocity is a crucial factor in lifesaving CVC installation. We were able to give tailored feedback to both stakeholders: we indicate process improvement potentials for the students and recommend the topics on which the instructor should focus in his classes. We detected that some students did not well memorize the order of process steps of the stages *ultrasound preparation*, *install guidewire* or *install catheter*. Therefore, we recommend the instructor to focus his classes on these topics. In general, the students miss routine in the basic process steps of the preparation phase. It would be good for the students to gain as much routine as neccessary, so they do not overthink each step. We also come to the conclusion that being close to the process model does not automatically imply that students are capable of performing well on a real-life CVC installation, as the factor time is important as well. Hence, on the special topic of CVC installation analysis, we would recommend to include the expert's process times directly in the conformance checking algorithm to give even more useful feedback.

Generally, we think that conformance checking has high potential to achieve process-oriented feedback to stakeholders, but we are aware of the fact that actual techniques are not sufficiently expressive regarding diagnosis. A large amount of manual analysis work is needed to extract understandable results from the algorithms. Future work should comprise expanding the repertoire of conformance checking algorithms, probably, there exist techniques that provide more intuitive results. This research area is still young, so we expect fast development in this topic.

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