Business Processes Modeling

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Chapter 1

Introduction

This report presents a comprehensive Business Process Modelling (BPM) and Workflow Net (WF-net) analysis of a structured process scenario set in the context of a painting school. The objective of this report is to model and evaluate the procedural dynamics through which the painting school manages student requests, learning appointments, and pedagogical interactions between students and teachers.

The process begins with a student initiating contact with the school, and requesting information about available courses. Upon selecting a course, the student is introduced to a teacher who coordinates and proposes the details of the first lesson. This initiates a negotiation loop until both parties agree on a suitable date and location. Each lesson includes preparatory tasks, guided artistic sessions, feedback loops, and post-lesson assignments to be completed and submitted digitally. The cycle continues with new appointments or ends with the student exiting the course. An optional path allows the student to initiate a new learning cycle at the end of the process.

To accurately reflect this scenario, the modeling efforts have been divided into three layers. First, the business process is depicted through BPMN, capturing the sequence flow, control flow constructs, and message exchanges. Second, the BPMN model is translated into a Workflow net expressed in Petri net notation, enabling a formal and executable representation of the process logic. Third, semantic analysis is performed using tools like WoPeD to assess the behavioral properties of the WorkFlow net in terms of soundness, deadlock-freeness, boundedness, and proper termination.

This report follows a structured methodology, beginning with a formal description and analysis of the BPMN model, proceeding with the transformation and evaluation of the corresponding WF-net, and concluding with a semantic validation and comparative assessment between the two representations.

Chapter 2

BPMN Model Analysis: Painting School

2.1 Introduction

The BPMN model, shown in Figure 2.1 of the Painting School scenario captures the collaborative and iterative nature of the learning process between a student and the school, mediated through interactions with a teacher. This BPMN model represents the choreography between two main participants, the Student and the School, each performing a series of structured and message-based activities that enable the creation, scheduling, and execution of the painting lessons. The model supports both the learning loop and the course lifecycle, from initiation to termination or potential renewal.

The primary objective of the BPMN model is to render an accurate and semantically rich description of the scenario by illustrating process flows, decision points, loops, and participant communications. To achieve this, the model is divided into two main lanes, each capturing the responsibilities and internal flows of the actors. Message flows connect the lanes to illustrate collaboration points, such as appointment scheduling, task submission, and payment management.

In the following subsections, we analyze the two lanes, Student and School, in detail, followed by an explanation of the message exchanges and their semantic implications within the process.

2.2 Student Lane

The Student lane, illustrated in Figure 2.2, models all the activities under the direct control and responsibility of the learner. This lane captures the lifecycle of participation. The activities can be grouped into the following main phases:

1. Course Selection Phase: The student begins by contacting the school and receiving a list of available courses. The selection process is performed internally and results in the student's course preference being communicated to the office.

2. Appointment Scheduling Loop: Once the teacher proposes a date and location for the lesson, the student can either accept it or suggest an alternative. This decision loop is done through an exclusive gateway. It ensures that the final agreement on the appointment is reached via, potentially, multiple interactions.

3. Preparation and Participation: Prior to each scheduled lesson, the student receives preparatory materials (techniques and tools), which they review. During the session, the student creates drafts under the teacher's guidance, asks questions if needed, and receives clarification.

4. Post-Session Activity: The student receives the teacher's proposal on the draft to finalize. Through an interaction loop similar to appointment scheduling, the final draft to complete is selected. The student finalizes, digitizes, and submits the draft.

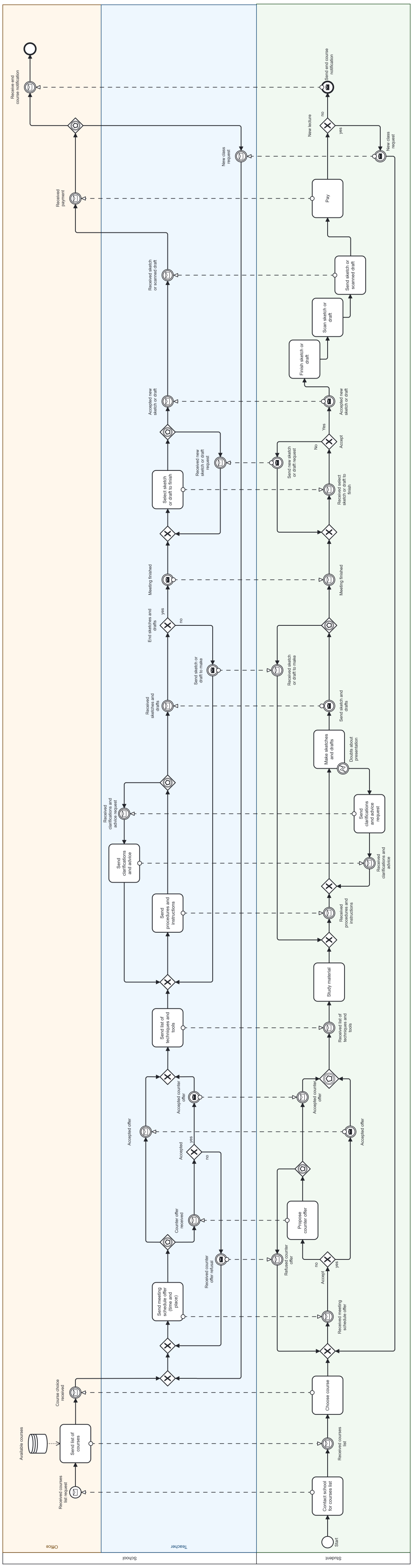

Figure 2.1: BPMN model

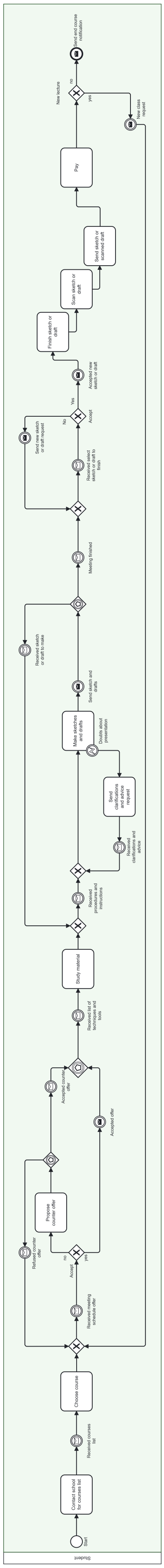

Figure 2.2: Student's lane

5. Payment and Next Steps: After submitting the task, the student sends an electronic payment to the office. Once payment is confirmed, the student can either initiate another appointment, restarting the loop, or decide to end the course. If they terminate it, they should inform the office. Otherwise, they re-enter the appointment scheduling cycle.

2.3 School Lane

The School lane, represented in 2.3 represents the institutional and instructional responsibilities, mediated mainly by the figure of the teacher. It includes both administrative and pedagogical tasks, including communication with the student, appointment handling, lesson preparation, and payment verification.

1. Course Offering and Enrollment: Upon receiving a contact request from a student, the office responds by sending a list of available courses. After the student selects a course, the office assigns a teacher and initiates communication regarding the schedule of the lessons.

2. Appointment Negotiation Loop: The school, via the teacher, proposes an initial date and location. If the student rejects the proposal, the school waits for a counterproposal and then either accepts or suggests a revision. This message based decision cycle continues until mutual agreement is reached.

3. Lesson Preparation and Supervision: Before each lesson, the teacher prepares a list of techniques and tools and sends it to the student. During the meeting, the teacher actively supervises the drafting process, explaining steps and answering student's inquiries.

4. Draft Selection and Feedback: At the end of the meeting, the teacher selects one of the student's drafts and proposes it for finalization. This step is also iterative, where the student might reject and ask for an alternative draft to finalize. Once accepted, the teacher awaits the completed, digitized draft from the student.

5. Payment Verification and Continuation: Upon receiving the final draft, the office awaits electronic payment. Once the payment is confirmed, the office informs the student of the possibility to schedule a new appointment or close the course, respecting the student's decision.

2.4 Inter-lane Interaction and Message Flow

The collaboration between the Student and School lanes is characterized by several message flows that facilitate the synchronization of parallel decision making processes. These message exchanges reflect:

- **Course Initiation:** From the student's request to the school's course offering.
- **Scheduling Negotiation:** Bidirectional communication on date and location proposals.
- **Preparation Materials:** Transmission of tools and technique lists from school to student.
- **Feedback and Clarifications:** Requests for help and explanations during the lesson.
- **Draft Selection Negotiation:** Proposal and acceptance of final draft selection.
- **Submission and Payment:** Final draft delivery from the student and payment verification by the office.
- **Closure Decision:** Student's decision to continue or terminate the course.

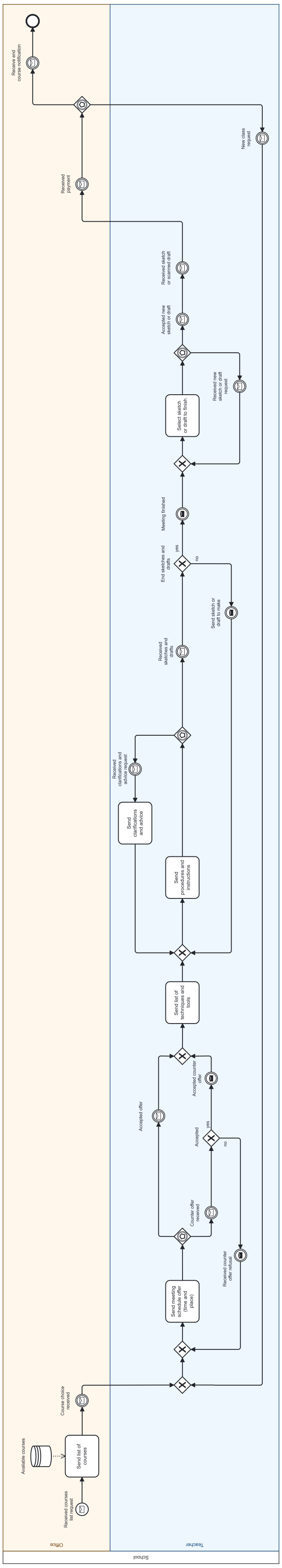

Figure 2.3: School's lane

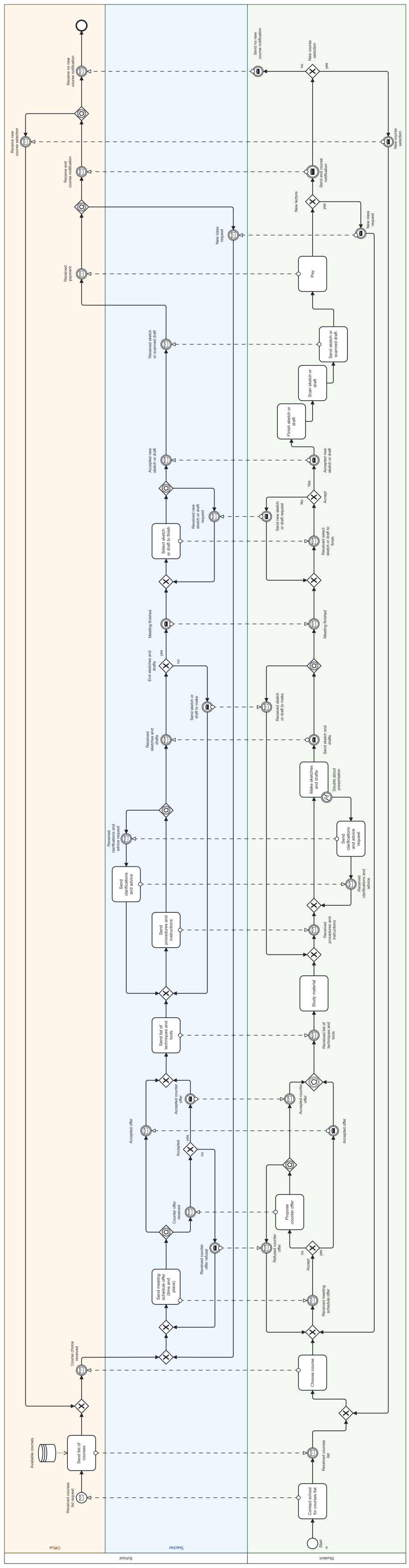

Figure 2.4: BPMN model variant

2.5 Variant

The modeled variant, shown in Figure 2.4, introduces an extension to the original scenario by allowing the Student, upon completing the current course, to initiate a new course. This addition reflects a more flexible lifecycle management, in which the process does not necessarily terminate after course completion, but may instead evolve into a recursive educational trajectory.

To capture this behavioral variant, modifications have been introduced in both the Student and Painting School lanes, as illustrated in Figures 2.5 and 2.6. In the **Student lane**, the change occurs after the intermediate throwing message event where the Student notifies the School of course completion. An exclusive gateway has been inserted immediately after this event. Through this, the Student either opts to terminate the course definitively, leading to the end event, or chooses to initiate a new learning course. In the latter case, a message flow is directed toward the School to communicate this intention, and the process control is routed back to the original gateway preceding the course selection phase.

In the School lane, a complementary adjustment has been made. Following the reception of the completion message, an event-based gateway has been added. This gateway captures the conditional nature of the continuation: it waits either for a new course notification from the Student, or, if no such message is received, allows the process to proceed to termination. If the new course message is received, the control flow is directed back to the initial gateway, where the process awaits the Student's course choice to resume the cycle.

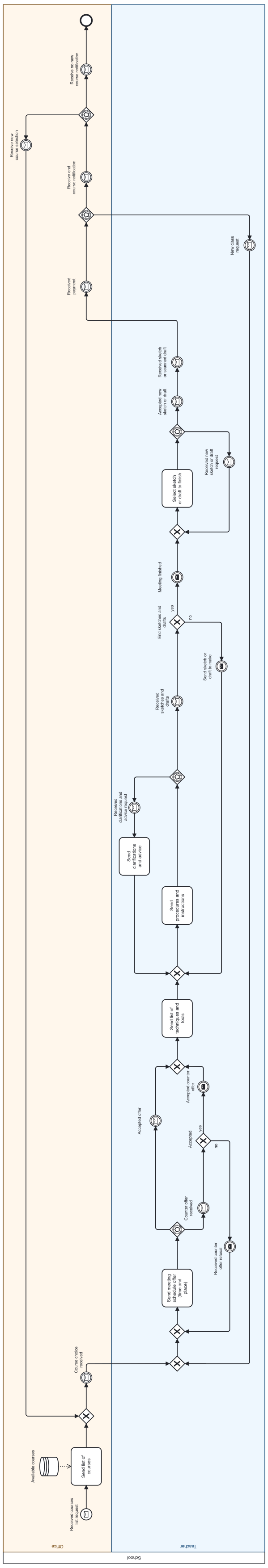

Figure 2.5: School variant

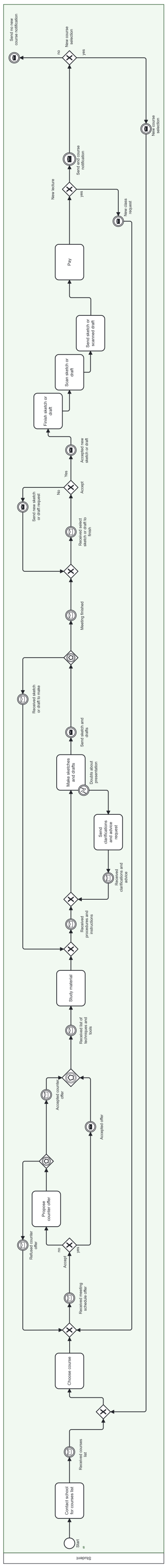

Figure 2.6: Student variant

Chapter 3

Work flow nets

The processes modeled using the BPMN were then transformed into a special type of Petri net, workflow nets. The utilization of Petri nets facilitates a more formal and mathematical representation, thereby enabling a more in depth analysis and verification of specific properties of the net and, consequently, of the process. The following rules were observed during the transformation from BPMN to workflow nets:

- Each task and event was replaced by a transition.
- Each sequence flow was replaced by a place.
- XOR splits and XOR joins were translated into places and transitions.
- Event based gateways were translated with a place followed by as many transitions as the possible alternatives that can occur.
- A single initial and final place was added.

The subsequent step is to analyze the workflow nets of the individual actors and then the complete workflow net. Finally, the coverability graphs of the networks, both in their basic and variant versions, are at the end of the report. The transformation and analysis were carried out using WoPeD.

All the coverability graphs of the described nets can be found at the bottom of the chapter, in Figures 3.9, 3.10, 3.11, 3.12.

3.1 Student

3.1.1 Structural Description of the Petri Net

The Petri net derived from the BPMN model, visible in Figure 3.1, represents the student side interactions within the painting school. It includes 37 places, 42 transitions, and 84 arcs, with no subprocesses or operators. Each place and transition lies on a path from a unique source place to a unique sink place, satisfying the definition of a Workflow Net (WF net). There are no wrongly used operators or free choice violations. The semantical analysis, described in the following sections, is represented in Figure 3.2

3.1.2 S-component Analysis and Well-Structuredness

The model is S-coverable, with a single S-component spanning all 79 nodes, confirming its behavioral cohesion. It is also well-structured, with no PT handles or TP handles, ensuring syntactic correctness of the control flow.

3.1.3 Soundness Properties

The net has exactly one source place (Start) and one sink place (End), with no arcs of non-standard weight and no transitions with empty presets or postsets. It forms a single connected and strongly connected component of 79 nodes, meaning that all elements are reachable and cyclically related.

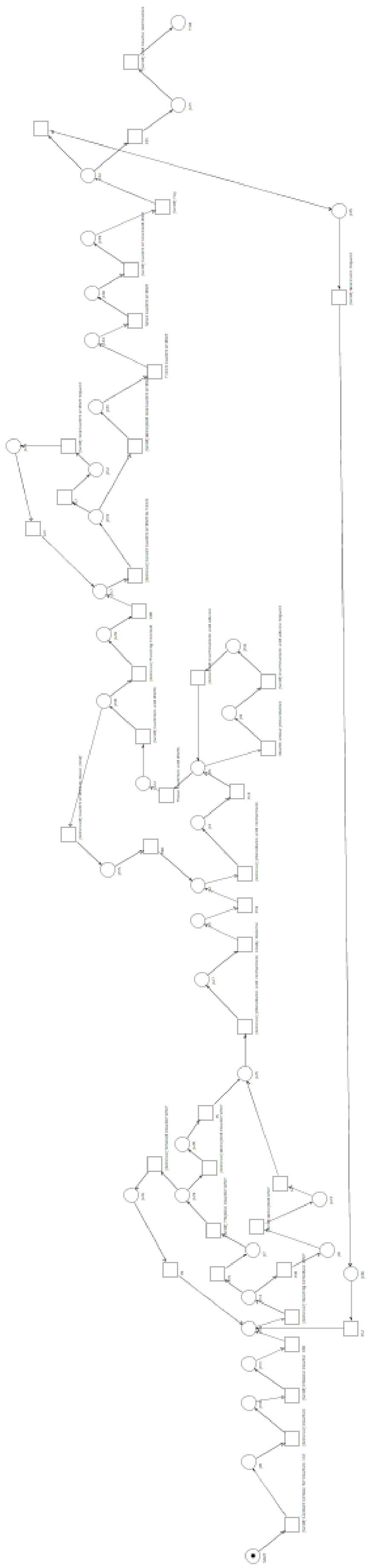

Figure 3.1: Student's WF-net

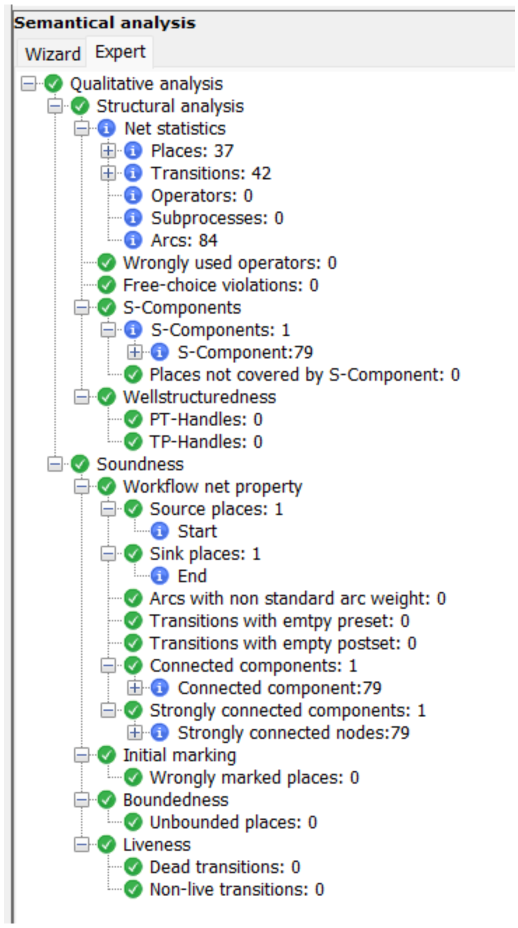

Figure 3.2: Student's WF-net Semantical analysis

3.1.4 Boundedness and Liveness

The net is bounded (no unbounded places), live (no dead or non live transitions), and correctly initialized (no wrongly marked places). These properties ensure stable execution and long-term operational correctness.

3.1.5 Conclusion

Overall, the model is sound, bounded, live, well-structured, and strongly connected, with no structural or behavioral issues identified.

3.2 School

3.2.1 Structural Description of the Petri Net

The Petri net derived from the BPMN model, visible in Figure 3.3, represents the school's side responsibilities in managing painting course interactions. It contains 31 places, 36 transitions, and 72 arcs, with no sub-processes or operators. Every node belongs to a path from a unique source place to a unique sink place, fulfilling the definition of a Workflow Net (WF net). The semantical analysis, described in the following sections, is represented in Figure 3.4.

3.2.2 S-component Analysis and Well-Structuredness

The net is S-coverable with a single S-component comprising all 67 elements, showing cohesive behavior across the model. It is well-structured, as no PT handles or TP handles are detected, ensuring clean and disciplined modeling of control flow.

3.2.3 Soundness Properties

The net includes one source place (Start) and one sink place (End), has no arcs with non-standard weights, and all transitions are properly defined with non-empty presets and postsets. The model forms a single connected and strongly connected component of 67 nodes, indicating that all parts of the process are reachable and interconnected.

3.2.4 Boundedness and Liveness

The net is bounded, with no places capable of accumulating an infinite number of tokens. It is live, with no dead or non-live transitions, and the initial marking is correct, as no places are wrongly marked. These properties support the net's reliability and repeatability in execution.

3.2.5 Conclusion

The School model is sound, bounded, live, well-structured, and strongly connected, with no structural or semantic inconsistencies identified.

3.3 Complete Workflow Net

3.3.1 Structural and Behavioral Analysis

The Petri net obtained by integrating all process perspectives (student, teacher, and office), visible in Figure 3.5, results in a comprehensive model composed of 88 places, 78 transitions, and 198 arcs. The transformation adheres to syntactic correctness: all nodes participate in paths from a unique source place to a unique sink place, ensuring the structure qualifies as a valid Workflow Net (WF-net). No wrongly used operators or malformed arcs are present, reflecting a well-executed composition of the individual models. The semantical analysis, described in the following sections, is represented in Figure 3.6.

At the behavioral level, the analysis highlights the presence of **six free-choice violations**, which occur in areas involving overlapping communication or decision scenarios. These include interactions such as:

- Clarifications and advice versus sketches and drafts reception,

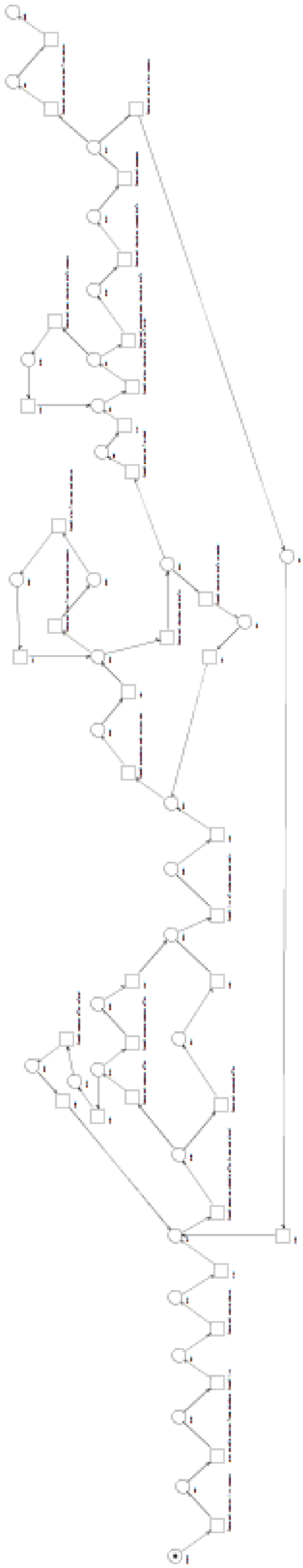

Figure 3.3: School's WF-net

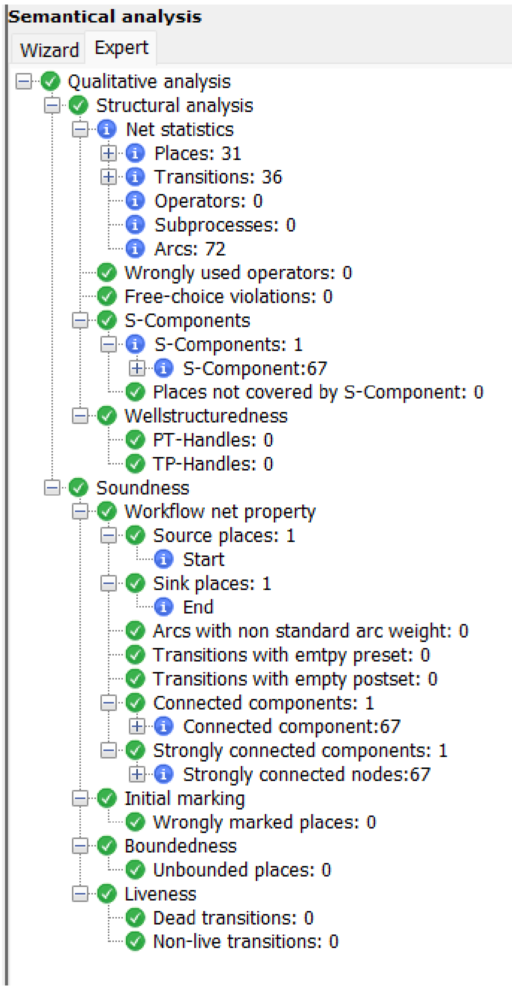

Figure 3.4: School's WF-net Semantical analysis

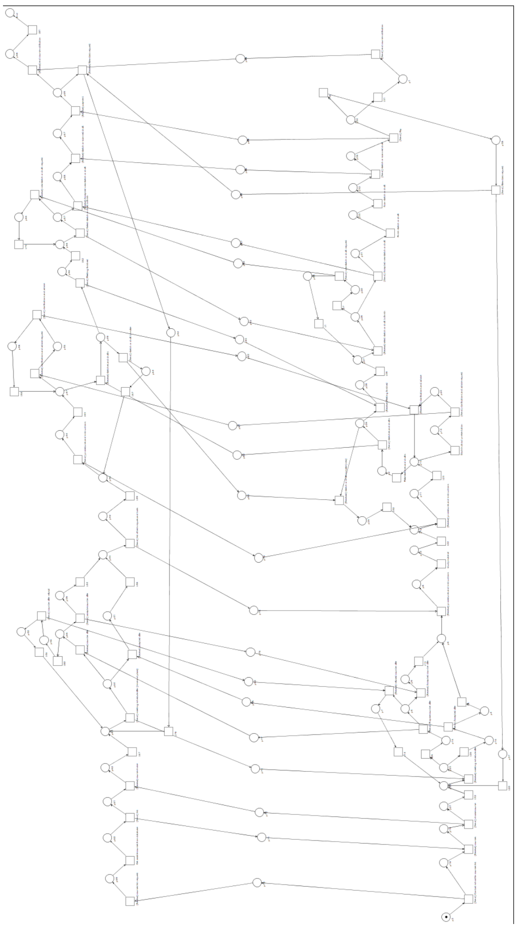

Figure 3.5: Complete Model's WF-net

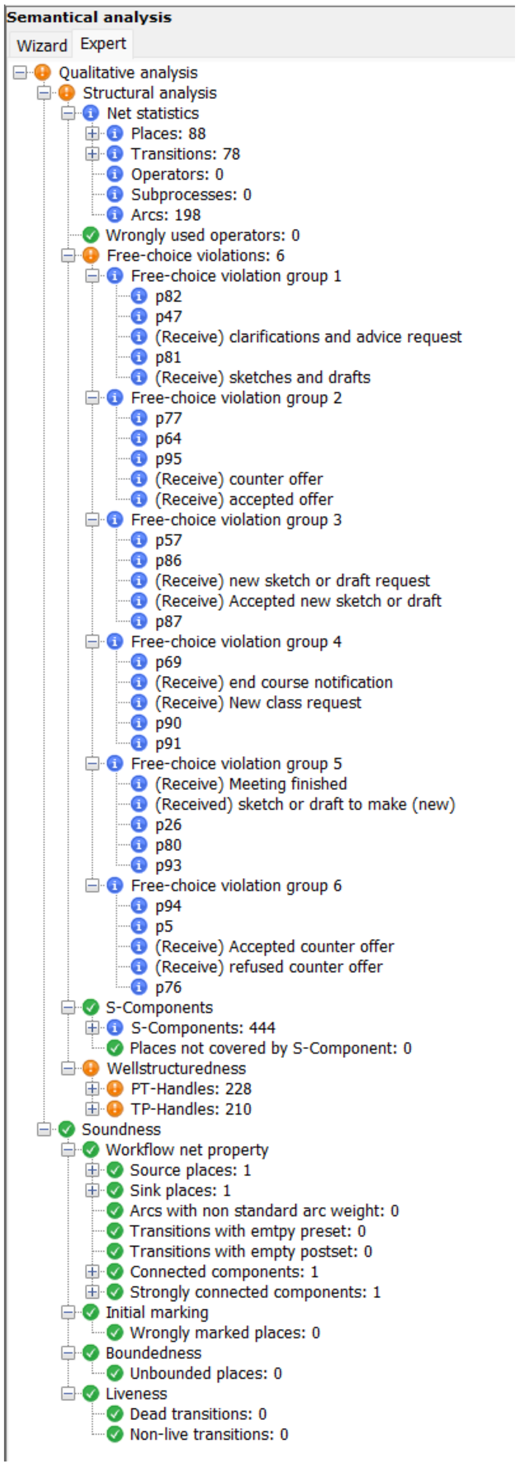

Figure 3.6: Complete Model's WF-net Semantical analysis

- Counter-offer and offer acceptance handling,
- Draft request and approval phases,
- Notifications regarding course start or end,
- Sketch submission and meeting closure,
- Responses to accepted or refused counter-offers.

While these deviations indicate that not all choices are independent in the model, they also reflect the interconnected nature of the integrated process. These points offer insights for refining control over parallel or conditional interactions in future iterations.

The model includes **444 S-components**, a consequence of its complexity and the many interaction paths. Although there is no single dominant S-component, the fact that all places are covered reflects full behavioral participation and correctness at the net level.

Regarding well structuredness, the model contains **228 PT-handles** and **210 TP-handles**. These do not affect soundness but suggest opportunities to simplify control-flow patterns, reduce branching ambiguity, and improve modularity. Their presence is not unexpected given the model's scale and the integration of three distinct perspectives.

3.3.2 Soundness and Execution Properties

Despite its structural involution, the model meets all key workflow net criteria. It includes exactly one source place (Start) and one sink place (End), has no non-standard arc weights, and all transitions are well-defined with valid presets and postsets. It forms a single connected and strongly connected component, and the net is correctly initialized. Furthermore, it is **bounded and live**, with no unbounded places or dead transitions, ensuring its suitability for safe and repeatable execution.

3.3.3 Conclusion

The complete model successfully integrates the individual perspectives into a merged and sound workflow net. While the analysis reveals structural complexity and certain free-choice and handle-related issues, these are consistent with the increased behavioral richness of the full process.

3.4 Variant Complete Workflow Net

3.4.1 Structural and Behavioral Analysis

The Petri net representing the variant of the complete process—integrating the student, school, and master, visible in Figure 3.7, workflows—consists of 93 places, 83 transitions, and 212 arcs. As with the previous model, it adheres to the syntactic requirements of a Workflow Net (WF-net): there is one source and one sink place, all transitions are connected, and no wrongly used operators or malformed arcs are detected. This confirms the structural validity of the model at a fundamental level. The semantical analysis, described in the following sections, is represented in Figure 3.8.

However, the behavioral analysis highlights the presence of **seven free-choice violations**, slightly more than in the base integration. These are localized in process segments where overlapping control or communication logic is used. Notable areas include:

- Course selection and no-course-notification,
- Counter-offer negotiation,
- Draft submission and meeting closure,
- New or end-of-course notifications,
- Clarification and sketch management exchanges.

These violations reflect situations where transitions share input places but do not preserve equal or disjoint presets. This is typical in rich collaborative settings and offers an indication for future refinements.

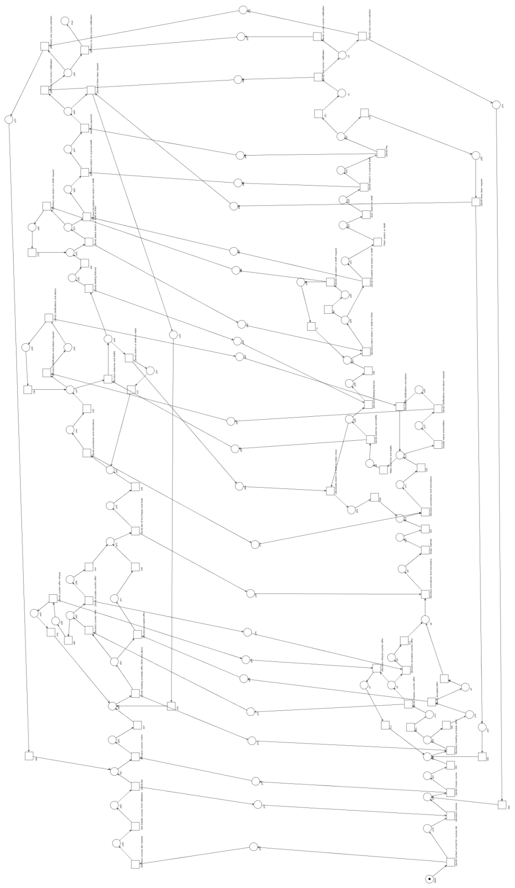

Figure 3.7: Complete Model variant's WF-net

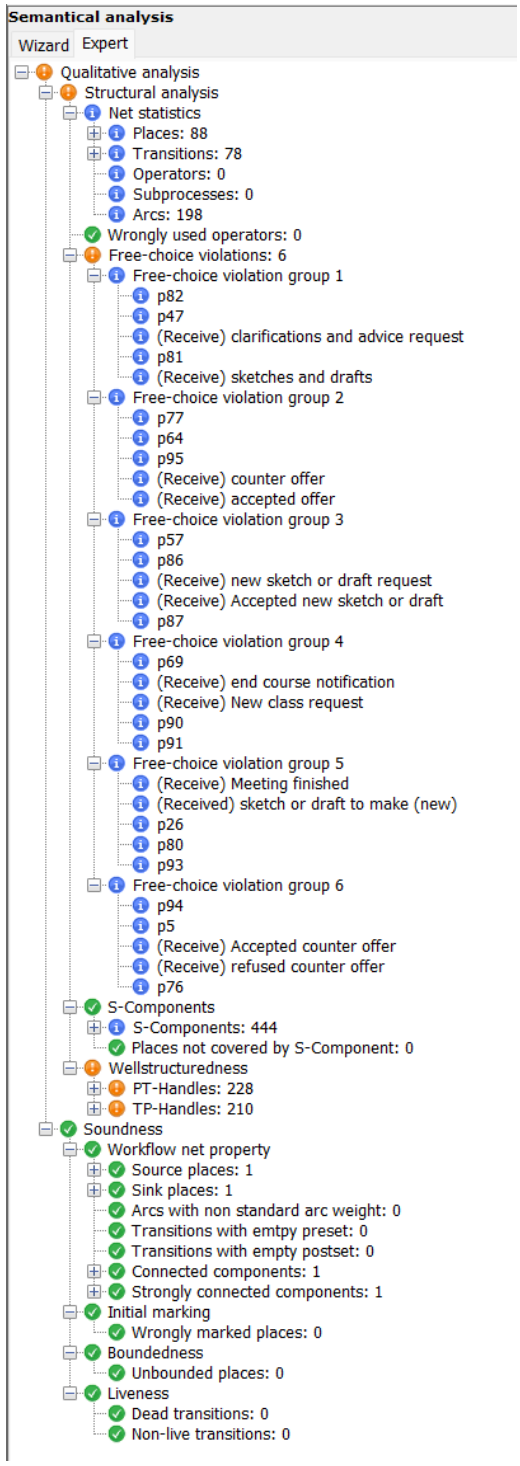

Figure 3.8: Complete Model variant's WF-net Semantical analysis

The net comprises **270 S-components**, which, while not uncommon for models of this scale, indicates distributed behavioral segments rather than a unified structure. All places are covered by at least one S-component, demonstrating full behavioral inclusion.

From a structural control-flow perspective, the analysis identifies **308 PT-handles** and **276 TP-handles**. They point to branching complexity and interaction density, both of which are expected in integrated models combining multiple concurrent workflows.

3.4.2 Soundness and Execution Properties

Despite the observed violations, the net satisfies all fundamental soundness properties. It features exactly one source and one sink place, and forms a single connected and strongly connected component consisting of 176 nodes. All transitions are well-defined with non-empty presets and postsets, and the model contains no arcs with non-standard weights. The initial marking is correct, and the model is both **bounded and live**, with no unbounded places, dead transitions, or incorrect markings, confirming its correctness from an execution standpoint.

3.4.3 Conclusion

This variant of the complete workflow net preserves technical soundness and achieves a high level of integration across all process participants, while introducing additional free-choice violations and control-flow complexity compared to the baseline model.

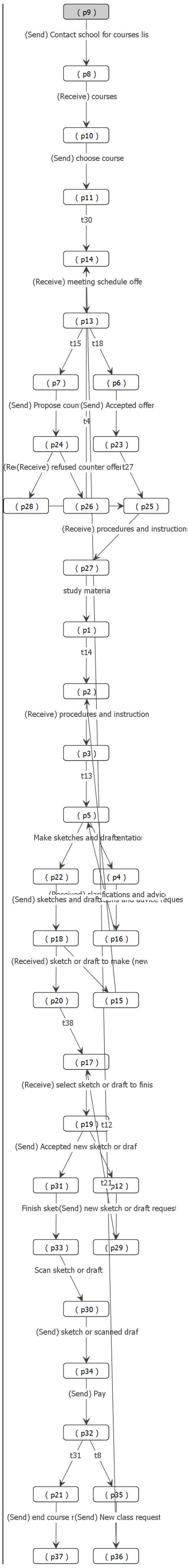

Figure 3.9: Coverability graph Student's WF-net

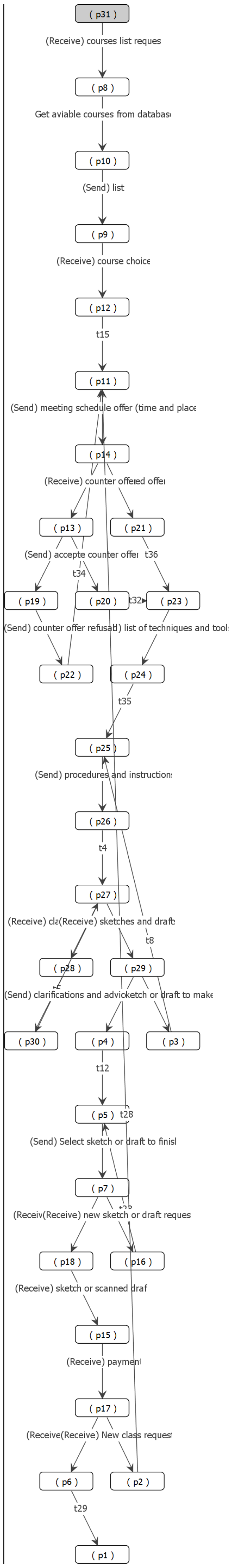

Figure 3.10: Coverability graph School's WF-net

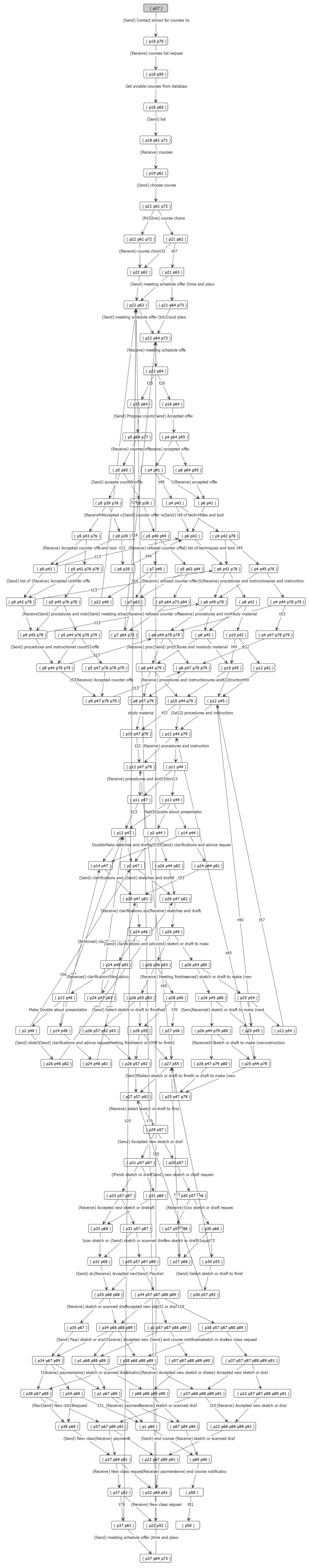

Figure 3.11: Coverability graph Complete Model's WF-net

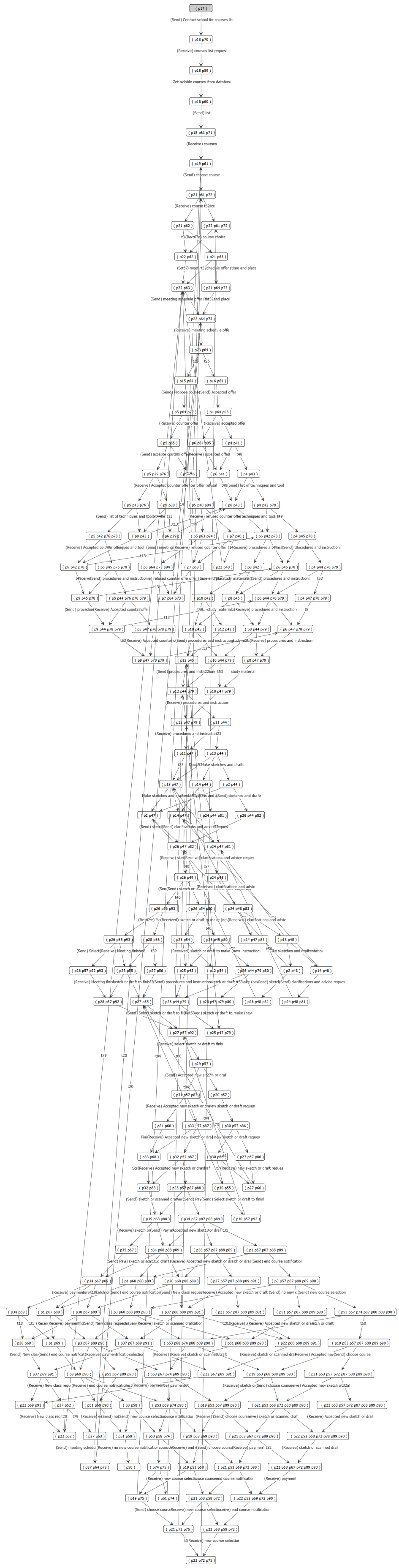

Figure 3.12: Coverability graph Complete Model variant's WF-net