# Combining Goal and Process Models for the Specification of Human-Robot Collaborations

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Abstract: Human-Robot collaboration enhances flexibility and efficiency in modern manufacturing. Collaborative robots work alongside human operators to combine robotic precision with human adaptability. A key challenge is defining task sequences, managing dependencies, and aligning workflows with strategic goals. This paper addresses this challenge by integrating goal models with process models. Goal models capture the "why," while process models define the "how" in operational workflows. Our approach systematically maps goals to tasks, ensuring clear traceability and cohesive task execution. We evaluate this method through a collaborative assembly use case. The integration refines task dependencies, improves coordination, and ensures alignment between goals and processes. This approach supports efficient human-robot collaboration in semi-automated manufacturing environments.

## 1 INTRODUCTION

Collaborative robots (cobots) play a key role in making manufacturing processes flexible. They work alongside other robotic systems to replace parts of traditional production lines and improve efficiency. Cobots are cost-effective and adaptable, enabling Human-Robot Collaboration (HRC) to meet specific manufacturing needs (Grau et al., 2020). Cobots are ideal for small batch sizes, where full automation is too expensive and inefficient. In such cases, semi-automated setups, where humans and cobots share tasks, provide a practical solution. This approach combines human adaptability with robotic precision to reduce costs and improve flexibility.

In HRC, human operators and cobots operate in close proximity. They work in parallel or simultaneously on the same tasks (Wang et al., 2020). Cobots assist by handing parts to human operators, or holding parts in position (Vysocky and Novak, 2016). Humans, on the other hand, contribute to more complex tasks that are difficult to automate (Weiss et al., 2021). It is crucial to plan this interaction in an early development phase to ensure that the cobot can work alongside the human safely and achieve all intended goals. To support this, model-based approaches provide structured methods for analyzing and specifying such collaborations. These approaches have already proven valuable in domains like industrial automation, automotive, and avionics (Estévez and Marcos, 2011; Böhm et al., 2021), where complex systems require early planning and clear task definitions to ensure success.

Goal modeling is an established approach in requirements engineering (Van Lamsweerde, 2001). It allows the analysis of goal fulfillment and conflicts among stakeholders and helps in understanding goals (hard goals), tasks, dependencies, and interactions between different systems (Horkoff and Yu, 2011). While goal modeling is useful in HRC (Daun et al., 2019), it lacks a clear description of the process logic in the interaction between human and cobot. In product assembly, the cobot and human operator have distinct tasks, some of which are interdependent while others can be performed independently. However, they must be performed in a specific order, which significantly impacts the success of the collaboration.

For example, in an assembly process, the cobot might pick and place parts, but the human operator can only proceed with the next step (like screwing parts together) once the parts are correctly placed. If the cobot places a part out of order or incorrectly, the human operator's task may be delayed or need to be

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repeated. Therefore, it is crucial to define and manage the task sequence early in the development. This ensures the process logic is clear and that the tasks align with the collaboration's goals.

In this paper, we propose an integrated approach that derives a process model directly from the goal model of a Human-Robot Collaborative Assembly (HRCA) process. We adopt a transformation methodology adapted from (Ortiz et al., 2024), systematically mapping the elements of goal models to constructs in process models (Business Process Model and Notation (BPMN)). This creates a clear and direct traceability between high-level strategic goals and their operational task execution within the process flow. By applying this approach to a use case of toy truck assembly, we demonstrate its effectiveness in specifying human-robot task dependencies, refining process steps, and ensuring cohesive task coordination. Thereby, this paper contributes an investigation into whether integrating goal models with BPMN improves the specification and management of HRCA by aligning strategic goals ("why") with operational workflows ("how"). Through our evaluation, we analyze the extent to which the integrated models facilitate better goal fulfillment, task traceability, and collaboration efficiency in semi-automated manufacturing environments.

Section 2 introduces works related to the concepts of the manufacturing industry and HRC, as well as model-based engineering and model integration. Section 3 then presents our three-stage approach, which begins with defining the objectives of an HRCA using a goal model. This is followed by deriving a BPMN from the goal model with the assistance of a transformation table and then refining it. The approach is evaluated in Section 4 with a case example, the assembly of a toy truck. Finally, Section 5 concludes the paper and outlines future work.

## 2 RELATED WORK

In recent years, cobots have become integral to flexible manufacturing, designed to interact with humans without safety barriers or protective cages (Matheson et al., 2019). While cobots offer the flexibility for quick, cost-effective layout changes, their effective deployment requires a deep understanding of their characteristics, which can be a barrier to widespread industry adoption. Key challenges include organizing teamwork, facilitating autonomous decisions, and balancing autonomy with human oversight in tasks requiring conscious judgment (Kemény et al., 2021).

### 2.1 Modeling Human-Robot Collaborations with Goal and Process Models

To establish safe and reliable HRC, a proper definition and analysis of HRC is needed in early stages of development. Therefore, goal modeling has been shown to be an adequate approach for modeling collaborative systems and has been successfully applied to HRC as well (Daun et al., 2019). In previous work, we have shown that goal models can particularly be used to identify and model high-level safety hazards of the collaboration (Manjunath et al., 2024), and to define digital twins of robotic systems (Jesus Raja et al., 2024). In addition, process information is crucial for managing cooperation with cobots (Cherubini et al., 2016), and are a vital basis for defining coordinated behaviors between multiple actors (Corradini et al., 2023; Bourr et al., 2021), as well as for ensuring safety in the process (Kranz et al., 2024). However, these models often focus on later development phases and may overlook specific HRC dynamics, as BPMN primarily emphasizes operational aspects over goal rationales (Ponsard and Darimont, 2019).

Goal and process models play complementary roles in improving task coordination and efficiency in HRC. The HRC approach demonstrates how goal models define strategic objectives, while process models represent the operational workflows to achieve them. The integration of the two ensures that high-level goals are directly linked to task-level activities, enabling effective collaboration between humans and robots (Lestingi and Longoni, 2016).

Chen et al. use process models to detail task sequences and dependencies, while goal models determine optimal task allocation between human and robotic agents (Chen et al., 2011). This ensures that each task contributes directly to the overall goal and balances workload effectively. Similarly, another approach highlights how goal models capture collaboration objectives and process models define the sequences and interactions necessary for their execution. This integration facilitates smooth transitions between tasks and clarifies roles and responsibilities (Malik and Bilberg, 2019).

A systematic review emphasizes the importance of integrating goal models to represent long-term goals and process models to outline detailed steps required to achieve these goals. This combined approach allows for better planning and coordination in shared human-robot workspaces, particularly in scenarios involving dynamic and complex workflows (Simões et al., 2022). These studies highlight how goal models define "what needs to be achieved," while process models specify “how tasks are executed,” enabling effective management of HRCA in industrial environments.

### 2.2 Combining Goal and Process Models

Combining goal models and process models provides complementary perspectives, offering a more detailed understanding of system requirements (Amyot et al., 2022). Approaches like User Requirements Notation (URN), which integrate goal modeling with process modeling, have been applied in various domains, though they often require adaptation for specific industries (Daniel Amyot, 2022; Chen, 2007). More recent work by Ortiz et al. (Ortiz et al., 2024) incorporates goal-oriented modeling with BPMN for microservice compositions, ensuring alignment with business goals through the modification of processes.

The URN, standardized by the International Telecommunication Union (ITU-T) in 2008 with improved versions in 2012 and 2018, combines goal modeling with process modeling, offering both a graphical and a textual syntax(Daniel Amyot, 2022). URN facilitates leveraging social modeling in process design and improvement efforts. Chen et al. proposed an approach utilizing URN to model goals and processes, incorporating key performance indicator models and integrating a business intelligence tool to monitor and measure business processes, with a focus on healthcare (Chen, 2007). However, its applicability beyond healthcare is limited, and it requires adaptation for broader business process evaluation. Ortiz et al. (Ortiz et al., 2024) introduces an approach that represents goals in BPMN pools using collapsed BPMN sub-processes and enables independent development and modification of micro-services by transforming Tropos diagrams into structured BPMN diagrams, ensuring alignment with business goals.

While URN has seen numerous applications in academia and industry, additional efforts and educational initiatives are necessary for broader mainstream adoption. Customization to specific domains proves valuable, enabling the use of domain-specific terminology and syntax, as well as the development of reusable assets (Daniel Amyot, 2022). The works discussed above primarily focus on specific domains, such as health and business. In contrast, our paper centers on industry automation, particularly in the context of HRCA.

## 3 PROPOSED APPROACH

A combination of goal and process models facilitates a coherent interconnection between the overarching objectives of the goal model and the intricate process tasks of the process model. We use the goal-oriented requirements language (GRL) to specify goals of the HRCA, as GRL has already been proven useful for HRC (e.g., (Daun et al., 2023)). For process models, we rely on BPMN as it is a commonly used language, and also has already been successfully applied in HRC (e.g., (Fernandes et al., 2021)). By mapping the notations of GRL and BPMN specifically for HRCA, we ensure that both models are consistent with one another.

A goal model can be employed to illustrate the overarching strategic objectives of an HRCA process, as well as the subordinate sub-objectives that must be accomplished in order to attain the respective overarching goal. Such sub-goals may be defined as hard goals, such as the assembly of sub-assemblies, which are necessary for the completion of the overall goal of assembling the finished product. Moreover, soft goals, such as safe assembly, can also be defined. To prevent the target models from becoming too complicated, they are often limited to a relatively short description of the tasks (hard goal ”assembly of sub-assemblies”, but not the individual steps required for this). In BPMN, the chronological process flow of HRCA can be represented in greater detail, with the option of including individual assembly steps.

Our approach is based on the work of (Ortiz et al., 2024), who integrate goal models with BPMN. In this work, we adopt this integrated approach to specify and manage HRCA, where a human operator and a cobot perform complementary tasks. The procedure for transforming a goal model to a BPMN is as follows:

1. A goal model is created for the overarching goals of the assembly process, as well as the necessary soft goals.
2. A first version of the BPMN is then created based on the transformation table in Figure 2, which is consistent with the previously created goal model.
3. The BPMN is refined by further specifying tasks.

In our current version, only hard goals are transferred from goal models to BPMNs. These objectives, which are tasks within the goal model, are also the main components of a process flow and can therefore be transferred with minimal effort. In contrast, ‘soft goals’ are characterized by their heterogeneity, which poses a challenge in the standardization of their integration into a process model.

### 3.1 Definition of HRCA Goals with Goal Models

A goal model is a framework used to represent high-level objectives and strategic goals within a system. It decomposes these objectives into smaller sub-goals and tasks, aligning the system's actions with the desired outcomes. Goal models are instrumental in capturing the broad goals of HRCA and breaking them down into specific tasks that human operators and robots need to execute to achieve the intended goals. These models help ensure that each task performed, whether by the human or the cobot, is contributing towards achieving the overarching goal.

The elements of a goal model for HRCA are:

- **Actors:** Usually the human and the cobot working together on the assembly. Furthermore, the system may be expanded to include additional actors, such as other tools or machines, or multiple humans or cobots.
- **Goals:** High-level objectives that represent the desired outcomes, such as "Assemble Final Product."
- **Sub-Goals:** Defined as hard goals, these are more specific objectives that support high-level goals, such as "Prepare Sub-Assembly".
- **Soft Goals:** Qualitative objectives, such as "Minimize Errors" or "Maximize Efficiency," that influence multiple tasks.
- **Tasks:** A breakdown of high-level goals into smaller, actionable items performed by the actors cobot and human.
- **Self-Dependencies:** Dependencies between two tasks or goals of an actor.
- **Dependencies:** The interdependence between two tasks or goals undertaken by different actors. Such dependencies may be either unidirectional, pertaining to assembly sequence dependencies, or bidirectional, denoting collaboration between human and cobot.

In HRCA, the goal model provides a structured approach for ensuring that the tasks performed by human operators and cobots align with the broader goals of the system. It helps articulate the overall purpose of the collaboration and ensures each action contributes to achieving that purpose.

The first step in our approach is to create a goal model that represents the high-level objectives and their decomposition into sub-goals and tasks. The goal model identifies the strategic objectives of the assembly process and links these objectives with the tasks that need to be performed by the human operator and the cobot.

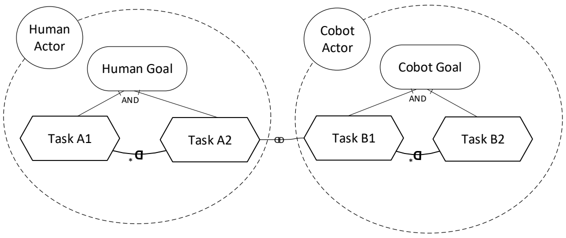

Figure 1: Goal Model of a typical HRCA, showing human and cobot as actors, their specific goals and the dependencies between the tasks.

Figure 1 shows an example of a typical HRCA. The scenario under consideration comprises two actors, namely the *Human Actor* and the *Cobot Actor*. Furthermore, a superordinate goal is set, the *Assembly of the final product*. This goal is broken down into two sub-goals, one for the human actor and one for the cobot. The aforementioned sub-goals are then subdivided into discrete tasks, designated *Task A1* and *Task A2* for the human actor and *Task B1* and *Task B2* for the cobot. Moreover, soft goals are defined at the sub-goal level. *Task A2* is dependent on *Task A1*, just as *Task B2* is dependent on *Task B1*. The completion of the cobot's *Task B1* is dependent on the completion of the human's *Task A2*. As the dependency is unidirectional, it is a result of the assembly sequence of the two tasks.

The goal model also considers soft goals that cannot be explicitly quantified but influence the overall collaboration process, such as "Minimize Errors" and "Maximize Efficiency". These goals guide the design of tasks and help to ensure that the collaboration remains effective and smooth.

### 3.2 Deriving a Process Model from the Goal Model

Figure 2 illustrates the correspondence between the notations of goal models and BPMNs. Our approach has been informed by the work of Ortiz et al. (Ortiz et al., 2024), which we have adapted and expanded to encompass the mapping of additional relevant notations for HRCA. The aforementioned table allows for the derivation of BPMNs from the previously created goal models. Figure 3 illustrates the BPMN derived from the goal model depicted in Figure 1. The initial step is to create a pool in the BPMN for each actor present in the goal model, which includes both *Human Actor* and *Cobot Actor*. Subsequently, the goals are translated into sub-pools, namely the *Human Goal* and the *Cobot Goal*. The tasks of the goal model are transformed into collapsed BPMN

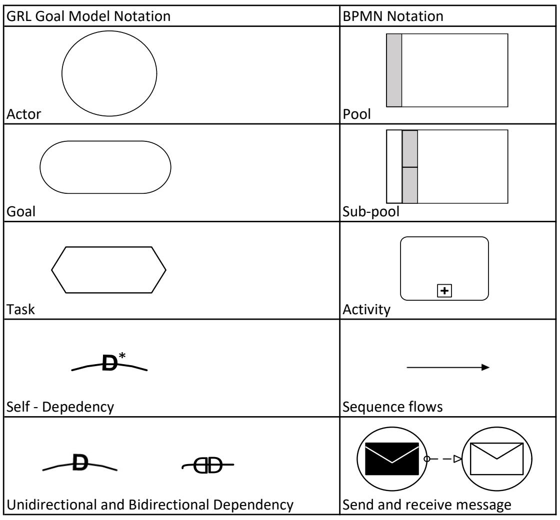

Figure 2: Transformation table to transform goal models into BPMNs. The mapping was adapted from (Ortiz et al., 2024) and extended to fit the purposes of HRCA.

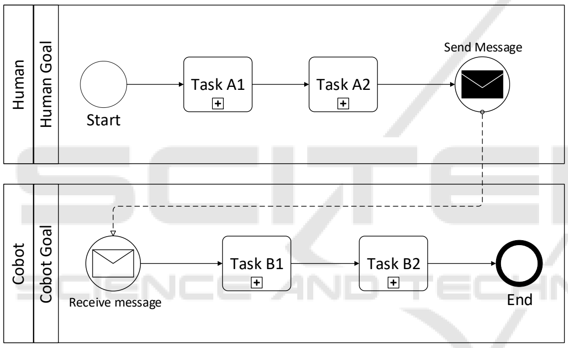

Figure 3: BPMN derived from a goal model.

sub-processes, designated as *Tasks A1, A2* and *Tasks B1, B2*. In the mapping of goals and tasks, we diverge from the approach proposed by Ortiz et al., who map goals to BPMN sub-processes without considering tasks. The sequence flows of the BPMN result from self-dependencies within the goal model (for example, *Task A2* is dependent on *Task A1*). Dependencies between two different actors are represented according to the mapping of Ortiz et al., with connected send and receive messages based on the type of dependency (for example, *Task B1* is dependent on *Task A2*).

The transformation of the goal model to the BPMN creates a direct mapping between high-level goals and operational tasks in the BPMN diagram. This framework ensures coherence and allows for seamless real-time coordination between strategic goals and operational tasks.

## 3.3 Refining the Process Model

BPMN is a widely used graphical language designed to represent the sequence and flow of tasks within a business or operational process. It provides a standardized way to model business processes, including task sequences, roles (human, robot), decision points, and interactions between process participants. In the context of HRCA, BPMN serves as an adequate tool for detailing the specific tasks, decision points, and dependencies that exist between the human operator and the cobot, ensuring smooth coordination and collaboration.

While goal models provide the high-level objectives of the collaboration, BPMN helps translate these strategic goals into a task flow, representing how those goals are achieved in practice. It captures the tasks performed by both the human and cobot actors, specifying the order of execution and how these tasks interrelate.

In the third and final step of our approach, we undertake a further refinement of the BPMN model derived from the goal model, defining the collapsed tasks with greater precision. This is done by elaborating on high-level tasks (e.g., A1, A2, B1 and B2) and refining them into their corresponding low-level subtasks (e.g., A1.1, A1.2, A2.1, A2.1, B1.1, B1.2, B2.1, B2.2). This enables the HRCA process flow to be described in a highly defined manner, encompassing tasks and intricate interactions. The link with the goal model is still in place, enabling conclusions to be drawn from the very precisely defined tasks and processes via their collapsed tasks back to the superordinate objectives of the goal model without overloading the goal model itself with these.

Figure 4 illustrates the refined BPMN derived from Figure 3. In this version, the activities are presented in greater detail, with all processes decomposed into sub-processes. For example, *Task A1* is further divided into *Tasks A1.1 and A1.2*. The same decomposition is applied to *Tasks A2, B1, and B2*. This refinement highlights the atomic tasks, helping to understand each step of the process. After the completion of A2.2 and B2.2, there is a gateway that checks if the tasks of the goal are completed so that the next set of tasks can be performed, or the process can be completed. For example, if task A2.2 is completed, the process moves on to B1.1; if not, it moves back to A1.1.

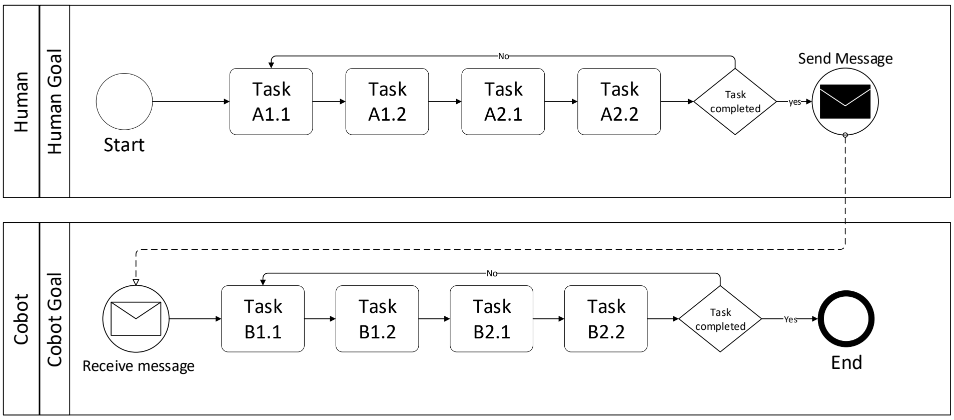

Figure 4: Refined BPMN.

# 4 EVALUATION

## 4.1 Case Example

We demonstrate how goal models and process models can be combined to specify HRCA, using the semi-automatic assembly of a toy truck as an example use case.

The assembly process includes operations starting from picking and preparing components to placing and screwing them. In the exemplary use case, a toy truck is assembled through collaboration between a human and a cobot. In the HRCA, the cobot initiates by picking the truck's load carrier from its storage area and positioning it upside down on the collaborative workspace. Subsequently, it proceeds to pick up the cabin and chassis, placing each in the workspace. The cobot then retrieves the front axle, securely holding it in place, and waits for the human operator to fix it.

While the cobot handles these initial steps, the human operator prepares a sub-assembly by prepared four axle holder by placing two screws in each. The human operator then fixes the front axle with the prepared axle holders with a screwdriver, and then repeats the process for the back axle.

## 4.2 Goal Model Creation

In the case of toy truck assembly, Figure 5 shows the goal model for the example use case, outlining the coordination between the human operator and the cobot. This model highlights the main tasks required to assemble the truck and shows the dependencies between these tasks. To achieve the main goal, the assembly of the toy truck, and three sub-goals need to be fulfilled: Prepare axle holders, prepare truck base and fix axles.

The two actors, human and cobot, have the following roles: **Human:** The human operator has two primary tasks in the assembly process: preparing the axle holders by picking and placing the parts and assemble them in the second step, and fixing the axles with a screwdriver. These tasks depend on each other, as picking and placing the parts is required for assembling the axle holders, which are needed for the fixation of the axles.

**Cobot:** The cobot has two primary tasks: first, preparing the truck base, and second, fixing the axles, by first placing the axle and then holding the axles in position, so the human operator can screw the axle holders into place. The cobot tasks also have self-dependencies, as the base of the truck needs to be assembled, to place the axles.

The example also has two interdependencies between tasks of different actors. The first one is an assembly sequence dependency, as the cobot has to place the axle first, so that the human operator can put the axle holders in place. The second one is a collaborative interaction, when the cobot holds the axle in place and the human operation screws the parts together. This interdependent actions ensure that the cobot's tasks align with the human operator's needs.

## 4.3 Deriving the BPMN from the Goal Model

Based on the goal model and system specifications, we derive a process model that outlines the tasks required for assembling the toy truck. This process model, illustrated in Figure 6, depicts the tasks to be undertaken by both the cobot and the human operator throughout the assembly process.

The process model shows how the tasks are related in terms of the overall assembly process (Figure 6).

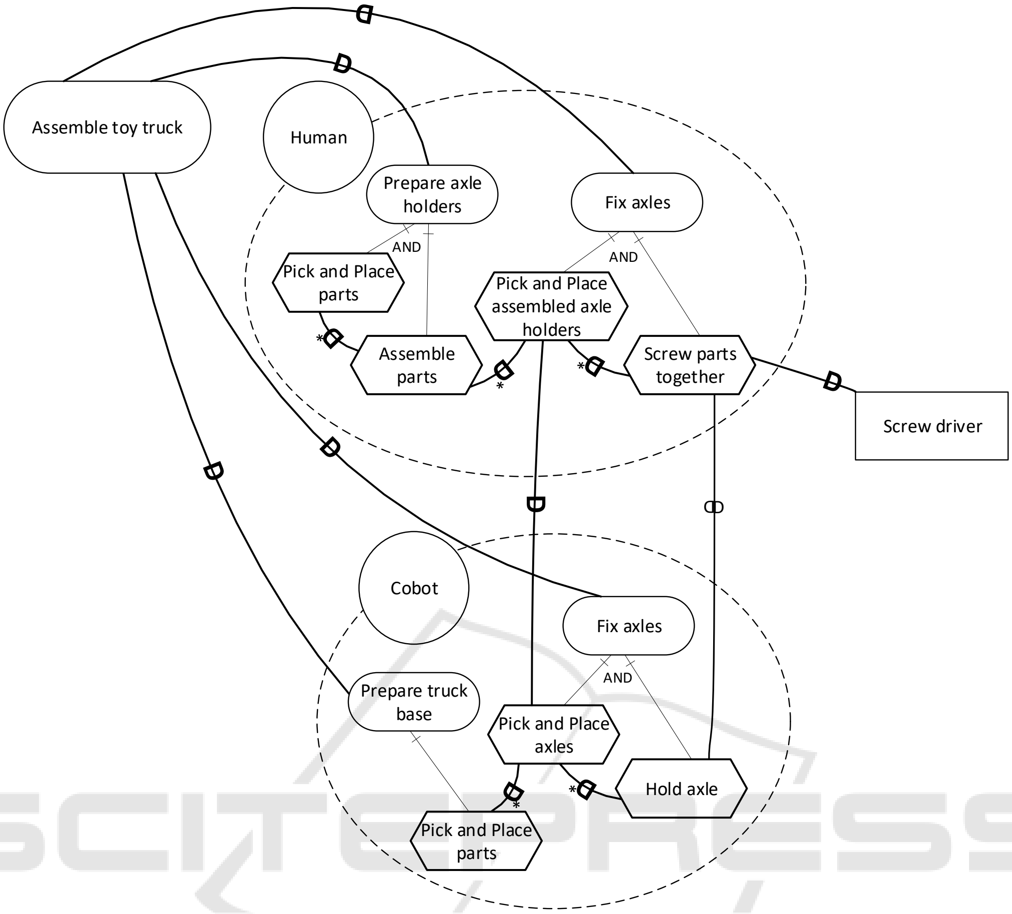

Figure 5: Goal model for the assembly of a toy truck.

Each actor (human operator and cobot) is represented as a BPMN pool, and their respective tasks are captured as BPMN activities within these pools. The tasks include the actions picking up components, placing them in the workspace, and screwing the axles into the truck body.

The main components of the BPMN are organized as follows:

**Cobot Pool:** This pool contains tasks that the cobot performs:

- “Pick and Place Parts”
- “Pick and Place Axles”
- “Hold Axles”

**Human Operator Pool:** This pool contains tasks that the human operator performs:

- “Pick and Place Parts”
- “Assemble Parts”
- “Pick and Place Assembled Parts”
- “Screw Parts together”

In this phase, message events are used to represent the interactions and dependencies between the two actors. For example, after the cobot places the axle, it sends a message to the human operator, prompting them to begin the next task of picking and placing the axle holders. Similarly, after the human operator finishes screwing, a message is sent back to the cobot, instructing it to proceed with the next task.

## 4.4 Refining the BPMN

Figure 7 shows the refined BPMN which was extended from Figure 6.

**Task Breakdown in BPMN:** The process model begins with the cobot executing a pick and place task, in which it picks up the load carrier and positions it within the collaborative workspace. The cobot then proceeds to execute additional pick and place operations for the cabin and chassis.

When the cobot picks and places the front axle, it holds the axle in position for the human operator to perform the required assembly task of securing the

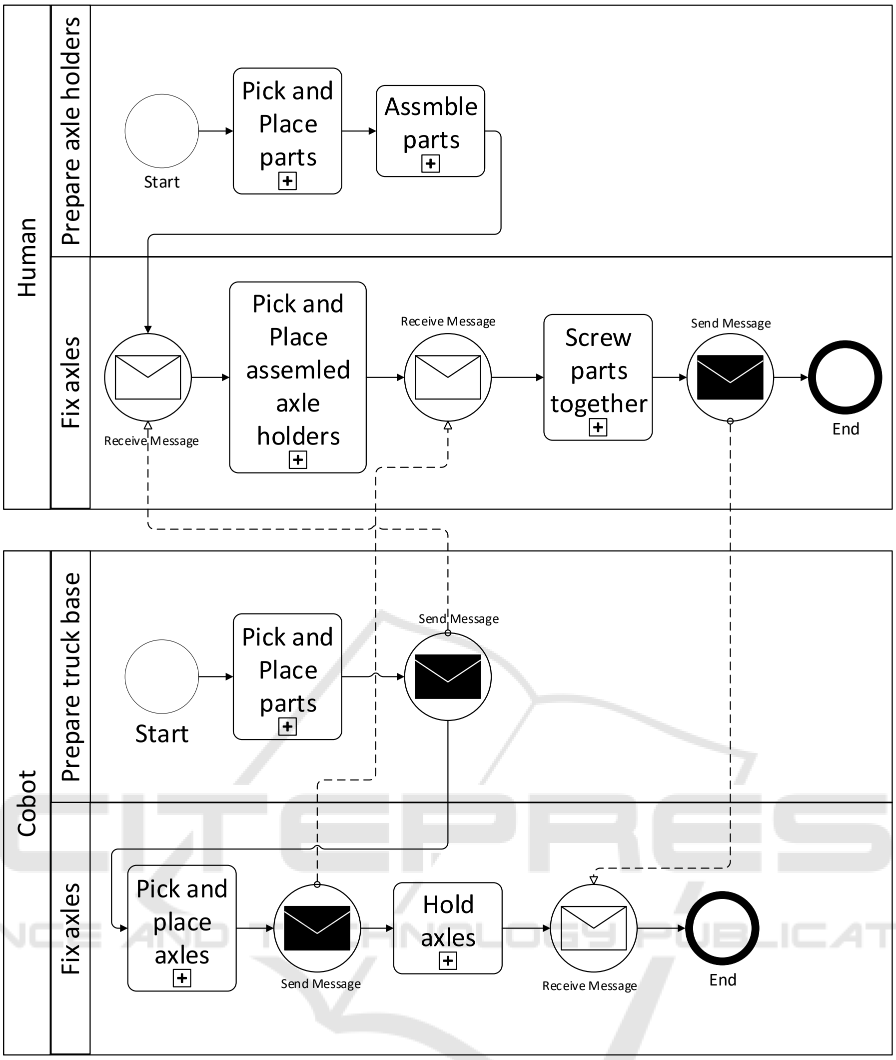

Figure 6: BPMN derived from the goal model of the truck use case.

axle to the truck body. The cobot remains in this holding position until it receives a confirmation message from the human operator indicating the completion of the task. Upon receiving this message, the cobot moves to the next instruction.

This task flow is repeated for the back axle.The completion of the cobot's tasks is signified by the BPMN end notation, which indicates that all components have been successfully assembled.

**Human Operator Tasks in BPMN:** The human operator begins the assembly process by preparing the axle holders for assembly. This involves picking the axle holders, inserting screws into each slot, and verifying that all slots are filled.

In the next phase the human operator's tasks, the prepared axle holders for the front axle are placed into position, with the cobot holding the axle in place. This collaboration ensures that the axle holders are positioned accurately. Once the human operator confirms the correct placement, he proceeds to use a screwdriver to secure the axle holders to the toy truck's body. After completing this task, the operator confirms the execution and a message is sent to the cobot to proceed with the next actions. This sequence is then repeated for the back axle.

At the end of the process, the human operator ensures that all four axle holders are securely screwed in place. This is represented by the gateway notation in BPMN, indicating a decision point in the process. If any axle holders are not correctly screwed in, the human operator must repeat the screwing tasks until all axle holders are correctly secured. Once all tasks are completed, the process is complete.

**Clarifying the Interaction Between Human and Cobot:** The BPMN provides clarity in illustrating the separation of work between the human operator and

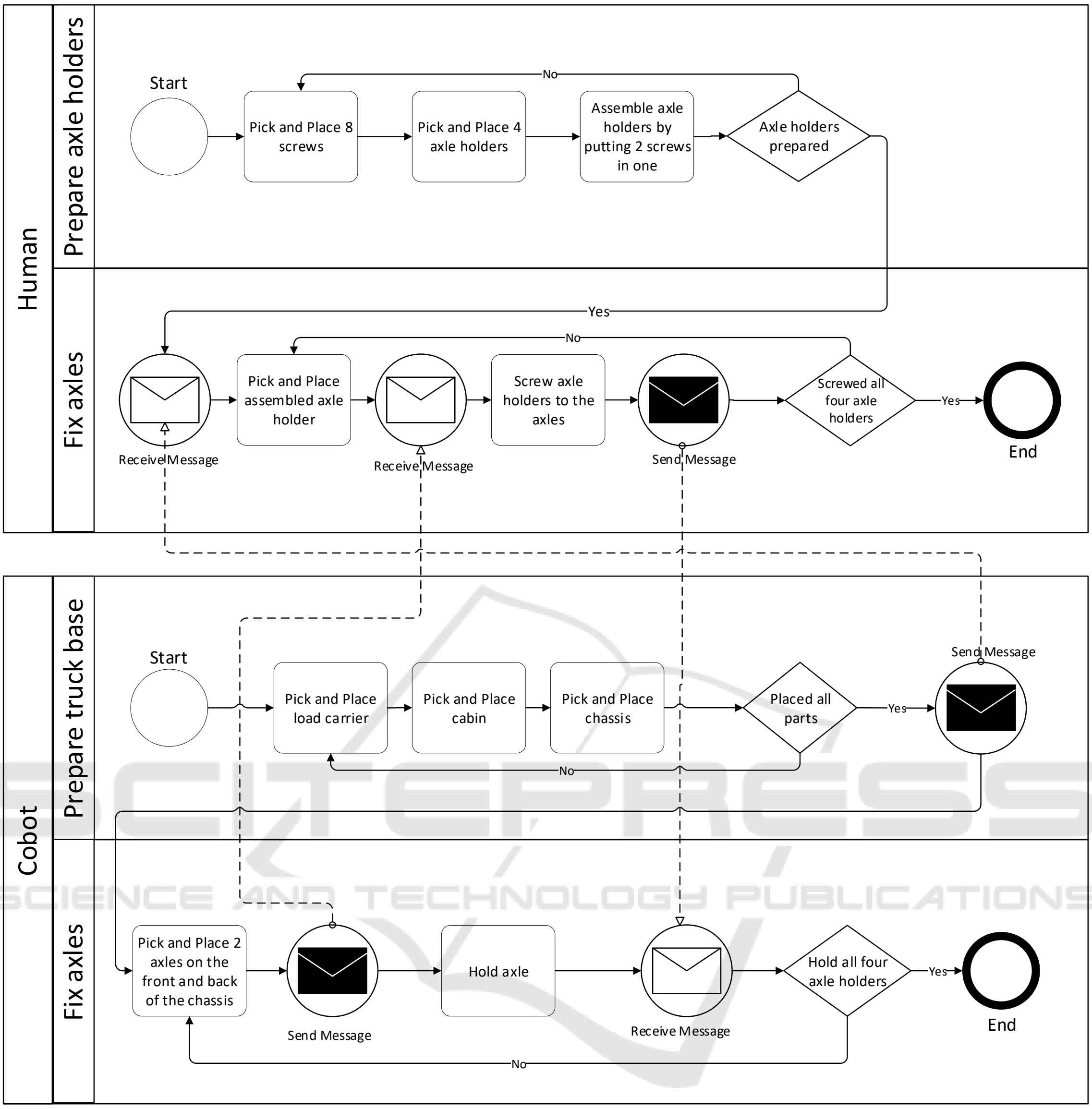

Figure 7: Refined BPMN of the truck use case.

the cobot, showing how their tasks are interdependent. BPMN also highlights the critical points where human oversight and robotic precision intersect to ensure the assembly process is both efficient and accurate. For instance: The human operator relies on the cobot to position components accurately, such as holding the axle in place during assembly. The cobot waits for confirmation from the human operator before proceeding, ensuring that the tasks are coordinated. This approach emphasizes the collaborative nature of the task flow, ensuring that both the cobot and human operator work together efficiently, with clear roles and responsibilities throughout the assembly process.

After the completion of every task in the process lane, there are gateways that check if the tasks of the human or cobot are complete in order to proceed with the assembly process. For example, in the 'Prepare Truck Base' lane, after all the pick and place tasks, the completion must be checked before sending the message; if not, the process goes back to 'Pick and Place Load Carrier.'

## 4.5 Discussion

The integration of goal models with BPMNs effectively addresses the limitations of both approaches, highlighting their complementary strengths and providing a comprehensive framework for HRCA. As demonstrated in the application example, goal models are excellent for identifying and emphasizing the essential tasks required to achieve an overall objective and how these tasks depend on each other. However, goal models alone lack the sequential detail necessary to fully understand how the tasks flow within a process. This is where BPMN adds value by providing a structured task flow and clearly delineating the order of actions from start to finish.

The clear mapping between the GRL goal model and the BPMN notations as shown in Figure 2 ensures the compliance of the BPMN with the goal model and offers several key benefits:

- **Enhanced Clarity and Comprehension:** The combined use of goal models and BPMN provides more detailed representation of the collaboration process. While goal models focus on identifying critical tasks, BPMN ensures the sequential flow of actions is captured, making it easier to understand how each task fits into the larger process and how they interact.
- **Improved Process Management:** By integrating the strategic focus of the goal model with the detailed assembly sequence provided by the BPMN, it becomes easier to manage and optimize HRCA. This approach helps identify potential safety hazards, areas for process improvement, and resource allocation issues.
- **Operational Efficiency:** By leveraging the detailed flow of the BPMN and the goal-oriented focus of the goal model, the integrated approach enables the development of more efficient HRCA. It ensures that the tasks of both the human operator and cobot are aligned, well-coordinated.
- **Comprehensive Documentation:** The combined approach ensures that both the high-level goals and detailed process steps are thoroughly documented. This is essential not only for understanding the HRCA, but also for process analysis, such as evaluating efficiency and identifying areas for continuous improvement.

In the present version, it is possible to derive a BPMN from a goal model and then refine it accordingly without affecting the mapping based on the transformation table. This allows the creation of an assembly sequence plan (BPMN) that is compliant with the overall assembly objectives (goal model).

One limitation of this approach is that the soft goals defined in the goal model are not translated into the BPMN, which is mainly due to the fact that the soft goals have a heterogeneous character. In the context of the truck use case, a possible soft goal of ‘safe interaction’ could be incorporated into the BPMN as an event. Conversely, ‘efficient interaction’ would likely exert influence on the process flow of the tasks. The implementation of a standardized notation in these scenarios pose a significant challenge. Nonetheless, it is imperative to acknowledge the importance of soft goals in the context of HRCA.

# 5 CONCLUSION & FUTURE WORK

HRC plays a crucial role in future manufacturing scenarios, where humans and robots collaborate on a task-level to jointly create a product. This collaboration enables semi-automation of flexible assembly processes for small batch sizes or allows the implementation of complex assembly tasks that are challenging to fully automate. Therefore, careful planning and task allocation are essential to ensure effective collaboration. This is particularly important during the early development stages, where analysis must determine whether HRC can effectively solve a particular task and identify critical aspects early on.

Recent works have demonstrated the utility of goal models in supporting the early analysis of collaborative and robotic systems. Goal models are excellent at identifying high-level objectives, but they often lack the sequential detail of the tasks required to achieve those goals. Therefore, in this paper, we introduced an integrated approach to derive process models directly from goal models for HRCA. This approach systematically transforms GRL-based goal models into BPMN process models. It creates clear traceability between high-level goals and detailed operational tasks. We apply this approach to a toy truck assembly use case. The results show improved task specification, process clarity, and task coordination. The integration of goal models and BPMNs align strategic goals with workflows. This alignment supports better goal fulfillment, clearer task traceability, and more efficient collaboration. It benefits semi-automated manufacturing environments by enhancing overall productivity and coordination. The abstract nature of the transformation table makes it possible for anyone to reuse the proposed integrated approach by following it and therefore achieving the expected outcomes.

In future work, we plan to extend this approach to include safety assessments in HRCA. Safety is critical in environments where humans and robots work closely together. Linking safety-related goals in goal models to BPMN constructs allows for early hazard detection. It also facilitates proactive safety monitoring throughout workflows. Additionally, we will extend our case study to a larger-scale assembly setting to demonstrate the scalability of our approach. We plan to conduct a broader evaluation of the transferability from goal models to BPMNs in more complex, industry-relevant scenarios, such as in the automotive or aerospace industries, where task dependencies in HRCA are more intricate. Finally, we plan to automate the overall framework using model-driven development methods.

During the evaluation of our truck assembly, it was realized that conclusions can be drawn not only from the goal models to the BPMN, but also from the refinement of the BPMN to a redesign of the goal model. This creates a bidirectional iterative process where both goal models and BPMN are continuously improved. By expanding this methodology, we aim to enhance the efficiency and effectiveness of HRCA, ensuring that human operators and robots collaborate more seamlessly to achieve the goals of modern manufacturing.

## REFERENCES

Amyot, D., Akhigbe, O., Baslyman, M., Ghanavati, S., Ghasemi, M., Hassine, J., Lessard, L., Mussbacher, G., Shen, K., and Yu, E. (2022). Combining goal modelling with business process modelling: Two decades of experience with the user requirements notation standard. *Enterprise Modelling and Information Systems Architectures (EMISAJ)*, 17:2–1.

Böhm, B., Böhm, W., Daun, M., Hayward, A., Kranz, S., Regnat, N., Schröck, S., Stierand, I., Vogelsang, A., Vollmar, J., Voss, S., Weyer, T., and Wortmann, A. (2021). Engineering of collaborative embedded systems. In Böhm, W., Broy, M., Klein, C., Pohl, K., Rumpe, B., and Schröck, S., editors, *Model-Based Engineering of Collaborative Embedded Systems*, pages 15–48. Springer.

Bourr, K., Corradini, F., Pettinari, S., Re, B., Rossi, L., and Tiezzi, F. (2021). Disciplined use of bpmn for mission modeling of multi-robot systems. In *Working Conference on the Practice of Enterprise Modelling*.

Chen, F., Sekiyama, K., Sasaki, H., Huang, J., Sun, B., and Fukuda, T. (2011). Assembly strategy modeling and selection for human and robot coordinated cell assembly. In *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 4670–4675. IEEE.

Chen, P. (2007). *Goal-oriented business process monitoring*. PhD thesis, Citeseer.

Cherubini, A., Passama, R., Crosnier, A., Lasnier, A., and Fraisse, P. (2016). Collaborative manufacturing with physical human–robot interaction. *Robotics and Computer-Integrated Manufacturing*, 40:1–13.

Corradini, F., Pettinari, S., Re, B., Rossi, L., and Tiezzi, F. (2023). A bpmn-driven framework for multi-robot system development. *Robotics and Autonomous Systems*, 160.

Daniel Amyot, O. A. (2022). Combining goal modelling with business process modelling. *Enterprise Modelling and Information Systems Architectures (EMISAJ)*.

Daun, M., Manjunath, M., and Jesus Raja, J. (2023). Safety analysis of human robot collaborations with grl goal models. In *International Conference on Conceptual Modeling*, pages 317–333. Springer.

Daun, M., Stenkova, V., Krajinski, L., Brings, J., Bandyszak, T., and Weyer, T. (2019). Goal modeling for collaborative groups of cyber-physical systems with grl: reflections on applicability and limitations based on two studies conducted in industry. In *Proceedings of the 34th ACM/SIGAPP Symposium on Applied Computing*, pages 1600–1609.

Estévez, E. and Marcos, M. (2011). Model-based validation of industrial control systems. *IEEE Transactions on Industrial Informatics*, 8(2):302–310.

Fernandes, J., Reis, J., Melão, N., Teixeira, L., and Amorim, M. (2021). The role of industry 4.0 and bpmn in the arise of condition-based and predictive maintenance: A case study in the automotive industry. *Applied Sciences*, 11(8):3438.

Grau, A., Indri, M., Bello, L. L., and Sauter, T. (2020). Robots in industry: The past, present, and future of a growing collaboration with humans. *IEEE Industrial Electronics Magazine*, 15(1):50–61.

Horkoff, J. and Yu, E. (2011). Analyzing goal models: different approaches and how to choose among them. In *Proceedings of the 2011 ACM Symposium on Applied Computing*, pages 675–682.

Jesus Raja, J., Manjunath, M., and Daun, M. (2024). Towards a goal-oriented approach for engineering digital twins of robotic systems. In *ENASE*, pages 466–473.

Kemény, Z., Váncza, J., Wang, L., and Wang, X. V. (2021). Human–robot collaboration in manufacturing: A multi-agent view. In *Advanced human-robot collaboration in manufacturing*, pages 3–41. Springer.

Kranz, P., Elbishbishy, S., Jesus Raja, J., and Daun, M. (2024). Supporting safety assessment in human-robot collaboration using process models. In *ER2024: Companion Proceedings of the 43rd International Conference on Conceptual Modeling: ER Forum, Special Topics,Posters and Demos, October 28-31, 2024, Pittsburgh, Pennsylvania, USA*, pages 136–140. CEUR Workshop Proceedings.

Lestingi, L. and Longoni, S. (2016). Hrc-team: A model-driven approach to formal verification and deployment of collaborative robotic applications.

Malik, A. A. and Bilberg, A. (2019). Developing a reference model for human–robot interaction. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 13(4):1541–1547.

Manjunath, M., Jesus Raja, J., and Daun, M. (2024). Early model-based safety analysis for collaborative robotic systems. *IEEE Transactions on Automation Science and Engineering*.

Matheson, E., Minto, R., Zampieri, E. G., Faccio, M., and Rosati, G. (2019). Human–robot collaboration in manufacturing applications: A review. *Robotics*, 8(4):100.

Ortiz, J., Torres, V., and Valderas, P. (2024). Combining goal-oriented and bpmn modelling to support distributed microservice compositions. In *ENASE*, pages 75–86.

Ponsard, C. and Darimont, R. (2019). Towards goal-oriented analysis and redesign of bpmn models. In *MODELSWARD*, pages 527–533.

Simões, A. C., Pinto, A., Santos, J., Pinheiro, S., and Romero, D. (2022). Designing human-robot collaboration (hrc) workspaces in industrial settings: A systematic literature review. *Journal of Manufacturing Systems*, 62:28–43.

Van Lamsweerde, A. (2001). Goal-oriented requirements engineering: A guided tour. In *Proceedings fifth ieee international symposium on requirements engineering*, pages 249–262. IEEE.

Vysocky, A. and Novak, P. (2016). Human-robot collaboration in industry. *MM Science Journal*, 9(2):903–906.

Wang, L., Liu, S., Liu, H., and Wang, X. V. (2020). Overview of human-robot collaboration in manufacturing. In *Proceedings of 5th International Conference on the Industry 4.0 Model for Advanced Manufacturing: AMP 2020*, pages 15–58. Springer.

Weiss, A., Wortmeier, A.-K., and Kubicek, B. (2021). Cobots in industry 4.0: A roadmap for future practice studies on human–robot collaboration. *IEEE Transactions on Human-Machine Systems*, 51(4):335–345.