Modification of Alpha++ for Discovering Collaboration Business Processes Containing Non-Free Choice

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***Abstract*— A business process is a series of activities or work that is structured and interrelated to solve a problem. Business Process Model Notation (BPMN) is a standard that often use to create a series of business processes. There are not only one or two processes in a business process, but many processes which cross each other. Processes which have activities related to one another are called collaborative business processes. Process mining techniques analyze a process model that is generated based on actual processes with a process model as the Standard Operational Procedure (SOP). Existing process mining techniques depict activities of each process without consider the linkages between activities in a process with another process. In addition, there is an issue that should be handled by process mining techniques, i.e. non-fee choice. This paper proposes a Modification of Alpha++ for discovering linkages of activities in collaboration business processes. Alpha++ is chosen because this algorithm can form non-free choice relationship. In the evaluation, the proposed Modification of Alpha++ will be compared with Alpha++, Inductive Miner, and Heuristic Miner. The evaluation shows the proposed Modification Alpha++ algorithm can model event log data correctly based on the proposed business process. Modification Alpha++ can find non-free choice constructs on the event log data. Modification Alpha++ gets the best calculation results for fitness, precision, and f-measure with a value of 1.**

Keywords*— *Alpha++, BPMN, Business Process

I. INTRODUCTION

A business process is a series of related structured activities that aim to solve a problem with the desired result [1]. Significant business processes create effective and efficient in the productivity of an organization [2]. The technology used for business process management continues to develop and be implemented on a small and large scale[3]. Business Process Model Notation (BPMN) is a modelling standard used to create a business process framework and workflow for a product or organization [4]. The use of BPMN facilitates analyzers to identify activities and becomes a basis of a simulation to predict future business processes [5]. In addition, BPMN also helps developers and stakeholders to understand the overall business processes. Furthermore, BPMN can minimize errors at the development stage, which impact costs [6].

A collaborative business process is a business process that allows organizations or other processes to communicate, interact, and carry out processes to achieve desired goals [7]. Collaborative business processes will enable a business process to be more complex and dependent on other processes [8]. In today's era, all organizations or companies generally use collaborative business processes by network communication because they need more facilities from another organization[9].

Process mining is a process that aims to extract event log data information from the results of business processes that have been run [10]–[12]. Process mining had done to check whether the activity process flow is following the designed business process[13], [14]. Missing design can be identified when the activity has been performed but is not recorded in the event log[15]. Some activities appear in mining results, but the sequence of activities does not describe these activities. The mining process results can diagnose bottlenecks in a processing activity carried out. An example of a tool used to carry out the mining process is ProM. Algorithms used for mining processes such as Alpha, Inductive Miner, and Heuristics Miner. In the mining process, there is a construction called non-free choice (NFC). NFC situation occurs when there is a mixture of choice and synchronization [10], [16]. The mix of choice and synchronization are not separate, so they are dependent on the final result [17]. The Alpha algorithm cannot find NFC constructs. Therefore, researchers chose the Alpha++ algorithm because it can discover NFC construction in the mining process. The Alpha++ algorithm is a refinement of the alpha algorithm.

In this study, this research introduces a new algorithm called Modification of Alpha++ algorithm that form a process model containing non-free choice based on collaborative business processes. Modification of Alpha++ is not only form sequence of activities in a business process, but also links between activities from different business processes. The links are called messages. The modification is adding several rules to inserting messages in the event log, so Alpha++ can determine messages aside from activities.

There are several steps of Modification of Alpha++. Firstly, an event log data is retrieved from the relational database by using proposed rules. Secondly, the obtained event log is discovered by Alpha++ algorithm. A process mining result obtained by using Modification of Alpha++ algorithm is compared with results obtained by Alpha++,

Inductive Miner, and Heuristic Miner algorithms. The researcher compares the fitness, precision, and f-measure values of model that generated by the algorithm.

The next explanation consists of several sections: Section II describes the basic concepts that underlie the research. Section III describes the proposed method. The experiment results are explained in section IV, and section V defines the conclusions of the study conducted.

II. Research Method

TABLE I. Example of Event Log

CaseID	Activity	Timestamps
C0001	Activity X	30/11/2020 10:00
C0001	Activity Y	30/11/2020 10:01
C0002	Activity X	30/11/2020 10:10
C0002	Activity Y	30/11/2020 10:11

TABLE II. Example of Event Log with Message

CaseID	Activity	Timestamps	Message To
C001	Activity X	30/11/2020 10:00	
C001	Message A	30/11/2020 10:01	Activity Y
C001	Activity Y	30/11/2020 10:02	
C002	Activity X	30/11/2020 10:10	
C002	Message B	30/11/2020 10:11	Activity Y
C002	Activity Y	30/11/2020 10:12	

A. *Event Log*

The event log is a collection of event data from a process, such as tasks, task actors, and task processing time [18]. Information from the event log can be used to evaluate a system. Using the event log, we can find out whether a built system is following the process flow of an organization[19]. Event log information uses to check fraud incidents that occur in the system[20], [21]. Process mining techniques are used to extract information from a collection of event data from a system so that it can be used to find out how well the flow of a system is with the workflow of an organization [10].

An example of event log data can be seen in TABLE I. In TABLE I, there is a CaseID column that shows the id of a series of processes. An Activity is an activity that is carried out and a Timestamp that illustrates the processing time. There are several cases and traces shown in the CaseID column of the existing event log sample data. Case and trace are two different things, where the case is a series of system activity events recorded by the event log, while a trace is a variation of various cases from the event log.

B. *Collaboration Business Process*

Business process collaboration is a business process in which some processes interact with each other between different pools [7], [22]. Allows other processes or organizations to interact with the business processes that have been created. This research uses the waste handling model, which can be seen in Fig. 2. There are 37 process activities, 12 messages, and two pools consisting of waste and documents.

Thirty seven process of that activity such as Choice Waste(CHOW), Put Waste in Recycle Bin(PWRCB), Put Waste in Safety Box(PWSB), Put Waste in Yellow Bin(PWYB), Put Waste in Brown Bin(PWBB), Put Waste in Purple Bin(PWPB), Put Waste in Red Bin(PWRB), Send Waste to Recycle Place(SWRP), Clean Waste(CW), Cleavage Waste(CVW), Soak Waste(SOW), Chop Waste(CHPW), Dry Waste(DW), Pack Waste(PW), Weight Waste(WW), Store Waste in TPS Recycle Waste(SWTRW), Take Waste by Industry(TWI), Send Waste to Industry(SWI), Shed Waste(SW), Send Waste to Incenerator(SWI), Burn Waste(BW), Pack Ashes(PA), Store Ashes in TPS Non-Recycle Waste(SATNRW), Take Ashes by P3(TAP3), and Send Ashes to P3(SAP3) in pool waste. There are Entry Recycle Waste Arrival Log(ERWAL), Entry Recycle Waste Processed Log(ERWPL), Entry Log of Recycle Waste in TPA(ELRWT), Create Waste Delivery Scheduler Offer (CWDSO), Get Approval for Waste Schedule(GAWS), Create Minute of Waste Shipments(CMWS), Entry Non-Recycle Waste Arrival Log(ENRWAL), Entry Ash of Waste Log(EAWL), Entry Log of Ashes in TPA(ELAT), Create Ashes Delivery Schedule Offer(CADSO), Get Approval for Waste Schedule Non-Recycle(GAWSNR), and Create Minutes of Ashes Shipments(CMAS) in pool document.

An example of a collaborative business process event log is shown in TABLE II. There is a column called Message To which shows the message delivery process between pools that causes a business process to have a form of collaboration with other processes that are different pools.

C. *Existing Algorithm of Process Mining*

In the discovery process, various problems arise during the modeling process. Many proposed algorithms solve the problem. Some of the widely proposed algorithms in the modeling process include the Alpha++, Inductive Miner, Heuristic Miner algorithm. The three proposed algorithms have their respective advantages and disadvantages in solving problems in an event log.

Alpha++ algorithm is a refinement algorithm from Alpha and Alpha+ algorithm. The Alpha++ algorithm can find an implicit activity or dependency [23]. For example, the invisible task (IT) consists of a skip, redo, and switch construction.

The Inductive Miner algorithm is a process discovery algorithm to build a business process model from the event log. This algorithm produces a Petri Net notated model. This algorithm's main advantage is that all models found are compatible with the block-structured workflow net systems, and the models are always fit [24].

The Heuristics Miner algorithm has the advantage mentioned in [25] that this algorithm can calculate the frequency. And for thousands of logs can determine which process is dominant and an unusual habit in a process.

D. *Non-Free Choice (NFC)*

Non-free Choice is an event where an option cannot be freely chosen[26]. An NFC event occurs in an activity related to other activities in the previous activity so that the choices in the last process cannot be selected freely [19]. It can be seen in Fig. 1. Activity E will not succeed if activity B is not complete. Likewise, Activity F will not succeed if activity C is not complete. Both E and F activities are NFC activities.

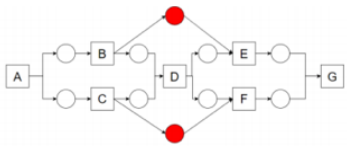

Fig. 1. Non-free Coice Construction

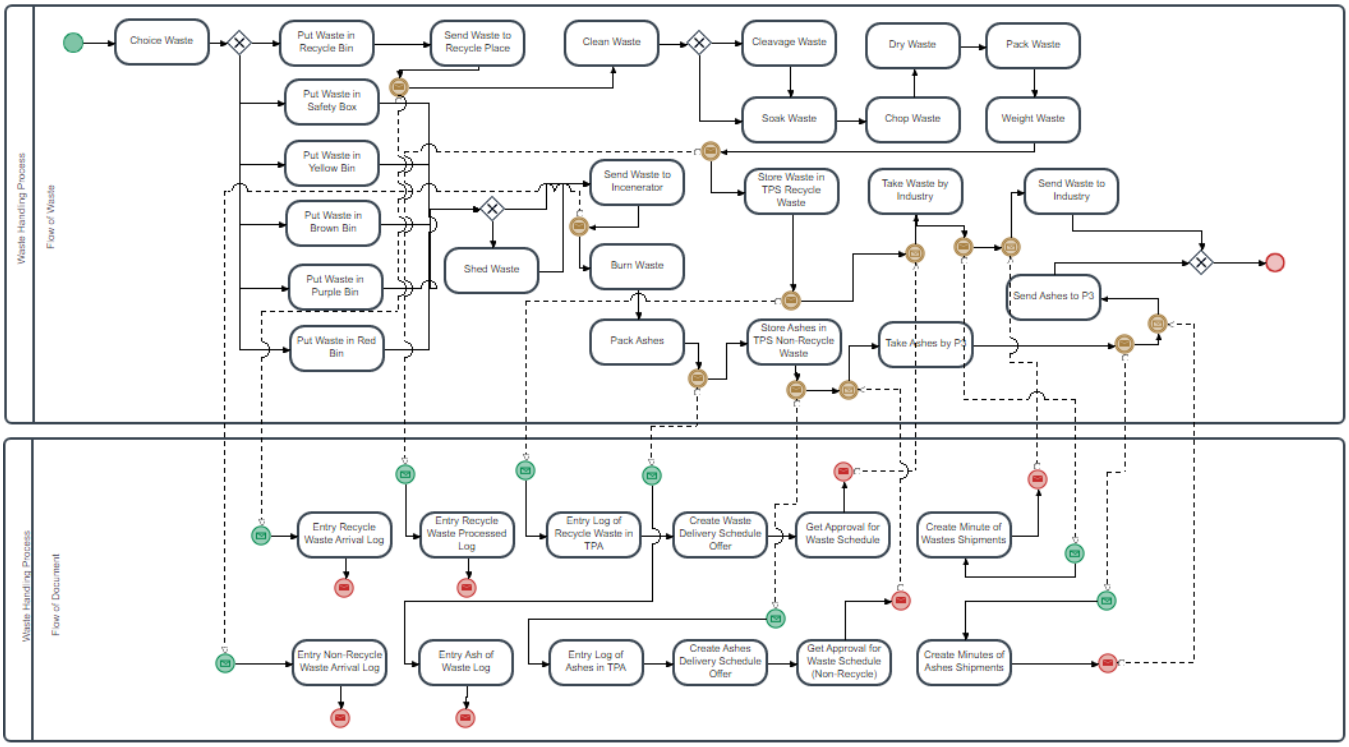

Fig. 2. Waste Handling Process Model

TABLE III. GET EVENT LOG WITH SQL QUERY

No	SQL Query
1	SELECT IF(bpmn_lane.LAN_NAME IS NULL, (
2	SELECT LAN_NAME FROM bpmn_lane
3	INNER JOIN bpmn_bound ON bpmn_lane.LAN_UID = bpmn_bound.BOU_ELEMENT
4	INNER JOIN app_cache_view ON bpmn_bound.ELEMENT_UID = app_cache_view.TAS_UID
5	WHERE app_cache_view.DEL_FINISH_DATE = message_application.MSGAPP_THROW_DATE),
6	bpmn_lane.LAN_NAME) as ProcessName,
7	message_application.APP_UID as CaseID, message_application.EVN_UID_THROW as Activity,
8	message_application.MSGAPP_THROW_DATE as Timestamp,
9	IF(users.USR_FIRSTNAME IS NULL, (
10	SELECT USR_FIRSTNAME FROM users
11	INNER JOIN app_cache_view ON users.USR_UID = app_cache_view.PREVIOUS_USR_UID
12	WHERE app_cache_view.DEL_FINISH_DATE = message_application.MSGAPP_THROW_DATE
13	LIMIT 1), users.USR_FIRSTNAME) AS Originator,
14	(SELECT task.TAS_TITLE FROM task INNER JOIN app_history ON task.TAS_UID = app_history.TAS_UID WHERE app_history.HISTORY_DATE > message_application.MSGAPP_THROW_DATE limit 1) As MessageTo
15	FROM message_application
16	INNER JOIN bpmn_event ON message_application.EVN_UID_THROW = bpmn_event.EVN_UID
17	INNER JOIN app_cache_view ON (IF (bpmn_event.EVN_TYPE = 'INTERMEDIATE', message_application.MSGAPP_THROW_DATE = app_cache_view.DEL_DELEGATE_DATE, message_application.MSGAPP_THROW_DATE = app_cache_view.APP_FINISH_DATE))
18	INNER JOIN task ON app_cache_view.TAS_UID = task.TAS_UID
19	LEFT JOIN bpmn_bound ON task.TAS_UID = bpmn_bound.ELEMENT_UID
20	LEFT JOIN bpmn_lane ON bpmn_bound.BOU_ELEMENT = bpmn_lane.LAN_UID
21	LEFT JOIN users ON app_cache_view.USR_UID = users.USR_UID
22	GROUP BY Timestamp
23	UNION ALL
24	SELECT bpmn_lane.LAN_NAME as ProcessName, app_history.APP_UID as CaseID, task.TAS_TITLE AS Activity, app_history.HISTORY_DATE AS Timestamp, users.USR_FIRSTNAME AS Originator, NULL as MessageTo
25	FROM bpmn_lane
26	INNER JOIN bpmn_bound ON bpmn_lane.LAN_UID = bpmn_bound.BOU_ELEMENT
27	INNER JOIN task ON bpmn_bound.ELEMENT_UID = task.TAS_UID
28	INNER JOIN app_history ON app_history.TAS_UID = task.TAS_UID
29	INNER JOIN users ON app_history.USR_UID = users.USR_UID
30	GROUP BY app_history.APP_UID, app_history.DEL_INDEX
31	ORDER BY Timestamp

III. PROPOSED METHOD

Alpha ++ modification purposed to display messages sent between activities in different process pools. The message that appears can be used to reference a collaboration between activity processes in other pools. Collaboration processes between different pools can be seen in Fig. 2.

This section describes the flow of research undertaken (Fig. 3). At the initial stage, the researcher collected even log data. The event log is modified to describe business process collaboration with the existing process discovery algorithm, i.e. Alpha++. The next step, a process model generated by Modification of Alpha++ is compared with those process models generated by other algorithms. The fitness, precision, and f-measure measurements are compared to find the best result.

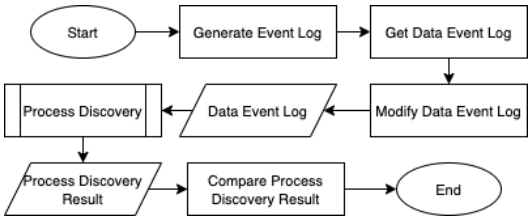

Fig. 3. Proposed Method

A. Generate Event Log

Process Maker application is used to run the proposed business process. Researchers use waste handling model as a reference for a series of process flows (can be seen in Fig. 2). Fig. 2 is a process model of waste handling process. Each process sequence path has been carried out to obtain complete event log data results. There are 37 process activities divided into two parts, 25 process activities in the waste pool and 12 process activities in the document pool. Thirteen traces have been executed to try all possible path.

B. Get Data Event Log

Retrieve event log data resulting from a series of processes that have been carried out in the process maker application. The event log data is taken from the application process maker database by executing the query that can be seen in TABLE III. From the results of the query execution, event log data are obtained in Comma Separated Value (CSV) format. In the event log, there is a column named Process Name, which represents the name of a process pool. CaseID functions to group the sequence of a series of processes. Activity shows the activities carried out. The timestamp indicates the time of a process. Originator serves to authenticate the user who carried out a process, and MessageTo shows the recipient of messages sent by the previous activity. For details on the results of event log data can be seen in TABLE IV.

C. Modifiy Event Log

Modifications are made by getting the data event log from the executing query (TABLE IV) and changing the CaseID column data. Event log modifications are made so that collaboration between business processes can be seen during the discovery process. The CaseID column, which was previously the code from the event log as in TABLE III, is converted into the process code that we have specified. The process code is changed to P00001, as in TABLE V. The purpose of modifying event logs is to unite a series of process flows separated by a pool. With a complete series of process flows, the collaboration between different process pools will be seen during discovery. The discovery process is carried out using Alpha++ with modified event log data.

TABLE IV. EVENT LOG FROM EXECUTING QUERY

PN	CID	ACT	TSM	OR	MT
FW	6083675325fc5106b7ab331011064742	CHW	30/11/2020 10:32	W	
FW	6083675325fc5106b7ab331011064742	PWRB	30/11/2020 10:34	W	
FW	6083675325fc5106b7ab331011064742	SWRP	30/11/2020 10:34	W	
FW	6083675325fc5106b7ab331011064742	5153024295fc51116aa2be2043821732	30/11/2020 10:34	W	ERWAL
FD	7216398555fc5112404e2c5080250097	ERWAL	30/11/2020 10:35	D	

TABLE V. MODIFICATION EVENT LOG

PN	CID	ACT	TSM	ORI	MT
FW	P0001	CHW	30/11/2020 10:32	W	
FW	P0001	PWRB	30/11/2020 10:34	W	
FW	P0001	SWRP	30/11/2020 10:34	W	
FW	P0001	5153024295fc51116aa2be2043821732	30/11/2020 10:34	W	ERWAL
FD	P0001	ERWAL	30/11/2020 10:35	D	

In TABLE IV and V, there are terms in columns and rows. In columns such as Process Name (PN), CaseID (CID), Activity (ACT), Timestamp (TSM), Originator (ORI), Message To (MT). On rows like Flow of Waste (FW), Flow of Document (FD), Waste (W), Document (D).

D. Process Discovery

Process discovery takes place after the event log data has been modification. In this session, the discovery process uses the Alpha++ algorithm to find NFC constructs on the model.

E. Compare Process Discovery Result

Measurements are made to the results of the discovery process. The modeling results are in the form of a Petri net, which is then analyzed to calculate how good the results of modeling are. measurements use fitness parameters, precision, and f-measure.

Fitness (Eq. 1) is used to calculate how precise the modeling is in capturing all cases in the event log data. Precision (Eq. 2) is used to see whether the process flow resulting from modeling is following the event log data. The F-measure (Eq. 4) is used for evaluations that display recall (Eq. 3) and precision results.

$$Fitness = \frac{n(case\_captured\_in\_model)}{n(case\_in\_log)} \quad (1)$$

where:

$n(case\_captured\_in\_model)$:
The real trace of the event log that the model has drawn

$n(case\_in\_log)$:
Whole trace contained in the event log

$$Precision = \frac{n(trace\_of\_mode\_in\_log)}{n(trace\_of\_model\_capture)} \quad (2)$$

where:
$n(trace\_of\_model\_in\_log)$:
The trace total, which in the event log is used into the model

$n(trace\_of\_model\_capture)$:
Full trace that can be modeled.

$$Recall = \frac{n(trace\_of\_model\_captured\_in\_log)}{n(trace\_of\_model\_captured)} \quad (3)$$

where:
$n(trace\_of\_model\_in\_log)$:
Full trace in the event log used into the model

$n(trace\_of\_model\_capture)$:
Full trace that can be modeled.

$$F - Measure = \frac{2(Recall \times Precision)}{(Recall + Precision)} \quad (4)$$

where:
$Recall$: Result of recall measurement
$Precision$: Result of precision measurement

IV. Result and Analysis

This section describes the results of the experiments that have been carried out. Starting from event log data, the discovery process, collaboration business process and result comparison using fitness, precision, and f-measure.

A. Result

The event log data used results from the waste handling model process, which can be seen in TABLE IV. In waste handling model (Fig. 2), there are 37 process activities in total. Thirty-seven process activities are separated into two parts, namely the waste pool and documents. There are 25 process activities in the waste sections, and in the document section, there are 12 process activities. Twelve paths are needed to try all conditions in all.

Researchers used the original even log data, which was discovered using the Alpha++, Inductive Miner, and Heuristic Miner algorithm. Some of the early activities appear in Fig. 4 such as ELAT, CMWS, CMAS, EAWL, ERWAL, ELRWT, ERWPL, CHOW, ENRWAL. In the waste handling business process, the process is not like Fig. 4. Fig. 4 is discovery result from Alpha++ algorithm. Alpha++ algorithm cannot model the event log properly based on comparing the waste handling model and the resulting model. The Alpha++ algorithm can produce a model with 20 traces, while the proposed business process contains 12 traces. The original event log modeling using the Alpha++ algorithm is not following the previously proposed business processes.

The Inductive Miner algorithm can model the original event log, as shown in Fig. 5. Fig. 5 is discovery result from Inductive Miner algorithm. Some activities appear at the beginning of the model, such as ELAT, CMWS, CMAS, EAWL, ERWAL, ELRWT, ERWPL, CHOW, ENRWAL. The waste handling model (Fig. 2) does not match the modeling results using the Inductive Miner algorithm. The sequence of processes between pools cannot be appropriately described in this model. There are 20 traces to the Inductive Miner model. There should be 12 traces as in the waste handling model. Using Inductive Miner's original event log algorithm failed to model event log data.

There are 12 traces from discovery results using the Heuristic Miner algorithm (Fig. 6). Fig. 6 is discovery result from Heuristic Miner algorithm. Many flows are not following the business process that was made before (Fig. 2). The pool flow cannot be connected and reads a new path that should be a process flow. The Heuristic Miner algorithm fails to model the event log according to the waste handling model. After the researcher modification the Alpha++ algorithm, the resulting model (Fig. 7) followed the waste handling model. The resulting model is following the sequence of activities referred to as the BPMN waste handling model (Fig. 2).

Like the first activity, namely Choice Waste, then the activities of Put Waste in Recycle Bin, Put Waste in Purple Bin to Put Waste in Red Bin are the same as the BPMN model that has been proposed. 12 traces correspond to the number of lines in the business process. The resulting sequence of activities and messages can be captured and successfully modeled. The researcher succeeded in using a Modification Alpha++ algorithm to model event logs such as the waste handling model and find non-free choice constructions. Modification Alpha++ can also describe the relationship between different activity pools via messages.

Collaboration in business processes can be seen in discovery results and process sequences, as shown in Fig. 7. A message or trigger leads to a process located in a different pool, but the process is a series of the same process. In this case, the researcher uses message triggering processes as a form of collaboration between different processes.

In waste handling model, there are two main pools, as shown in Fig. 2, namely the upper pool called waste and the lower pool called document. Message exchange occurs between the upper and lower pools. In the Send Waste to Recycle Place activity in the waste pool, there is a yellow message sign, which means sending a message to the Entry Recycle Waste Arrival Log activity in the document pool, which is marked with a green message, which means the message recipient.

The discovery result using the Modification of Alpha++ algorithm successfully captures the collaboration process in a series of operations, as in Fig. 8. In Fig. 8, the discovery event log results with Modification Alpha++ algorithm. A collaboration process occurs when the Send Waste to Recycle Place (SWRP) activity sends a message marked with an activity with a code. Activities with codes represent messages sent between Send Waste to Recycle Place (SWRP) activities to Entry Recycle Waste Arrival Logs (ERWAL). The two activities are located in different pools, so it can be said that the ongoing process is a collaborative business process. Fig. 2 is a description of BPMN, and Fig. 8 the piece of discovery results.

B. Analysis

By using Modification of Alpha++ algorithm, the discovery results show that the sequence of processes and

collaboration processes correctly modeled. The discovery model results with the waste handling model is the same process sequence.

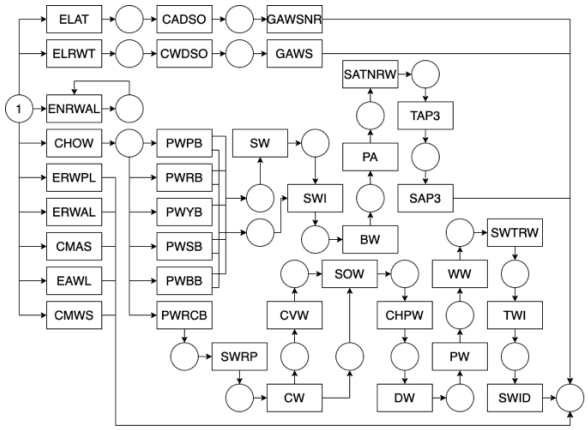

Fig. 4. Result of Process Discovery with Alpha++

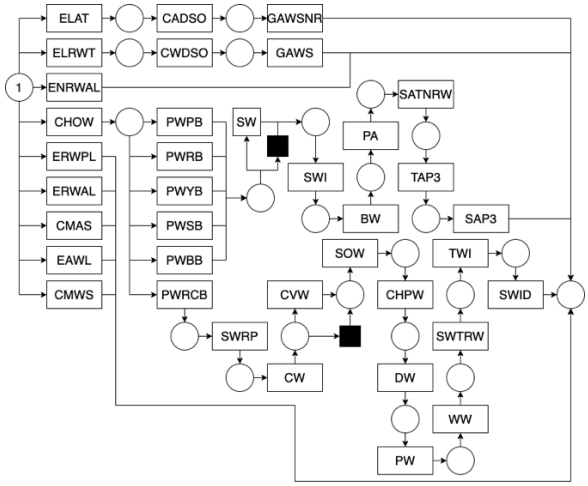

Fig. 5. Result of Process Discovery with Inductive Miner

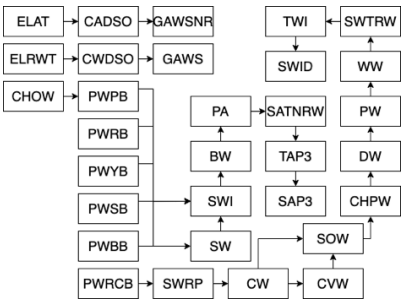

Fig. 6. Result of Process Discovery with Heuristic Miner

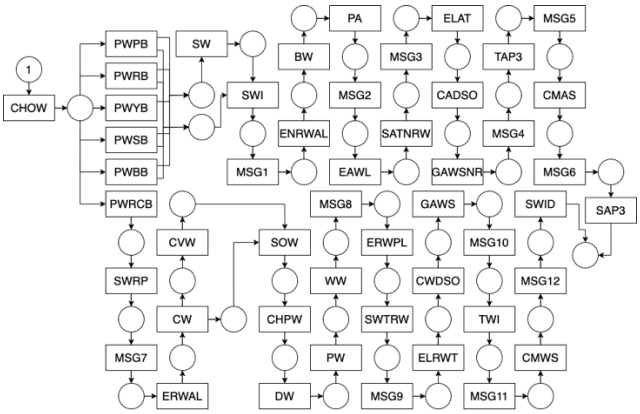

Fig. 7. Result of Process Discovery with Modification Alpha++

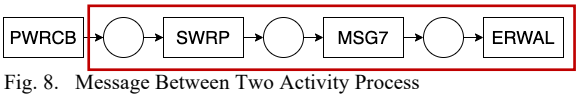

Fig. 8. Message Between Two Activity Process

TABLE VI. MEASUREMENT RESULT OF FITNESS, PRECISION, AND F-MEASURE

Algorithm	Fitness	Precision	F-Measure
Modification of Alpha++	1	1	1
Alpha++	0	0	0
Inductive Miner	0	0	0
Heuristic Miner	0	0	0

The researcher uses fitness measures, precision, and f-measures from the discovery results. TABLE VI shows the fitness, precision, and f-measure calculations. In the Alpha++, Inductive Miner, the Heuristic Miner algorithm is 0 for each value. The resulting model does not describe the collaboration process flow trace between pools using messages as the waste handling model (Fig. 2). Only Modification of Alpha++ algorithm can describe the activity relationship between pools using messages (Fig. 7). The Alpha++ can discover NFC construction, and the result of fitness, precision, and f-measure is 1. The best results are in Modification of Alpha++ algorithm.

V. CONCLUSION

In this study, the researchers proposed Modification of Alpha++ algorithm to describe business process collaboration in the waste handling model. The Modification of Alpha++ algorithm that the researcher suggests can model the event log data correctly. The Modification Alpha++ modelling result is compared with the waste handling model having the same process flow.

The calculation of fitness, precision, and f-measure produces the best value in Modification of Alpha++ algorithm that we propose, compared to the Alpha++, Inductive Miner, Heuristic Miner algorithm modelling. In further research, Modification of Alpha++ algorithm will be modified as a graph-based method, so event log data and process models can be drawn in one application platform.

In the case of research that has been done, it has not paid attention to the noise in the log data obtained. The size of the log data used is relatively small so that it does not accommodate large-scale data sizes (big data).

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REFERENCES

[1] R. S. Aguilar-Savén, "Business process modelling: Review and framework," *International Journal of Production Economics*, vol. 90, no. 2, pp. 129–149, 2004, doi: 10.1016/S0925-5273(03)00102-6.

[2] I. G. Anugrah and R. Sarno, "Business Process model similarity analysis using hybrid PLSA and WDAG methods," *Proceedings of 2016 International Conference on Information and Communication Technology and Systems, ICTS 2016*, pp. 231–236, 2017, doi: 10.1109/ICTS.2016.7910304.

[3] R. Sarno, H. Ginardi, E. W. Pamungkas, and D. Sunaryono, "Clustering of ERP business process fragments," *Proceeding - 2013 International Conference on Computer, Control, Informatics and Its Applications: "Recent Challenges in Computer, Control and Informatics", IC3INA 2013*, pp. 319–324, 2013, doi: 10.1109/IC3INA.2013.6819194.

[4] M. Chinosi and A. Trombetta, "BPMN: An introduction to the standard," *Computer Standards and Interfaces*, vol. 34, no. 1, pp. 124–134, 2012, doi: 10.1016/j.csi.2011.06.002.

[5] P. Y. H. Wong and J. Gibbons, "A process semantics for BPMN," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 5256 LNCS, pp. 355–374, 2008, doi: 10.1007/978-3-540-88194-0-22.

[6] R. M. Dijkman, M. Dumas, and C. Ouyang, "Semantics and analysis of business process models in BPMN," *Information and Software Technology*, vol. 50, no. 12, pp. 1281–1294, 2008, doi: 10.1016/j.infsof.2008.02.006.

[7] L. Zhang, Y. Lu, and F. Xu, "Unified modelling and analysis of collaboration business process based on Petri nets and Pi calculus," *IET Software*, vol. 4, no. 5, pp. 303–317, 2010, doi: 10.1049/iet-sen.2008.0062.

[8] J. Y. Jung, W. Hur, S. H. Kang, and H. Kim, "Business process choreography for B2B collaboration," *IEEE Internet Computing*, vol. 8, no. 1, pp. 37–45, 2004, doi: 10.1109/MIC.2004.1260702.

[9] Q. Mo, W. Song, F. Dai, L. Lin, and T. Li, "Development of Collaborative Business Processes: A Correctness Enforcement Approach," *IEEE Transactions on Services Computing*, vol. 1374, no. c, pp. 1–14, 2019, doi: 10.1109/TSC.2019.2961346.

[10] L. Wen, W. M. P. Van Der Aalst, J. Wang, and J. Sun, "Mining process models with non-free-choice constructs," *Data Mining and Knowledge Discovery*, vol. 15, no. 2, pp. 145–180, 2007, doi: 10.1007/s10618-007-0065-y.

[11] W. Van Der Aalst *et al.*, "Process mining manifesto," *Lecture Notes in Business Information Processing*, vol. 99 LNBIP, no. PART 1, pp. 169–194, 2012, doi: 10.1007/978-3-642-28108-2_19.

[12] Y. A. Effendi and R. Sarno, "Parallel process discovery using a new Time-Based Alpha++ Miner," *IIUM Engineering Journal*, vol. 21, no. 1, pp. 126–141, 2020, doi: 10.31436/iiumej.v21i1.1173.

[13] Y. Setiawan, K. R. Sungkono, and R. Sarno, "A new similarity method based on weighted graph models for matching parallel business process models," *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 5, pp. 267–276, 2020, doi: 10.22266/ijies2020.1031.24.

[14] R. Sarno and K. R. Sungkono, "A survey of graph-based algorithms for discovering business processes," *International Journal of Advances in Intelligent Informatics*, vol. 5, no. 2, pp. 137–149, 2019, doi: 10.26555/ijain.v5i2.296.

[15] A. Cahyapratama, K. R. Sungkono, and R. Sarno, "Gap analysis business process model by using structural similarity," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 1, pp. 124–134, 2019, doi: 10.11591/ijeecs.v18.i1.pp124-134.

[16] R. Sarno and K. R. Sungkono, "Coupled Hidden Markov Model for Process Discovery of Non-Free Choice and Invisible Prime Tasks," *Procedia Computer Science*, vol. 124, pp. 134–141, 2017, doi: 10.1016/j.procs.2017.12.139.

[17] Q. Guo, L. Wen, J. Wang, Z. Yan, and P. S. Yu, "Mining invisible tasks in non-free-choice constructs," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2015, vol. 9253, pp. 109–125, doi: 10.1007/978-3-319-23063-4_7.

[18] L. Hakim, R. Sarno, and K. R. Sungkono, "Modified Alpha++ algorithm for discovering the hybrid of non-free choice and invisible task of business processes," *International Journal of Intelligent Engineering and Systems*, vol. 12, no. 3, pp. 31–40, 2019, doi: 10.22266/ijies2019.0630.04.

[19] K. R. Sungkono and R. Sarno, "Constructing control-flow patterns containing invisible task and non-free choice based on declarative model," *International Journal of Innovative Computing, Information and Control*, vol. 14, no. 4, pp. 1285–1299, 2018, doi: 10.24507/ijicic.14.04.1285.

[20] R. Vaarandi, M. Kont, and M. Pihelgas, "Event log analysis with the LogCluster tool," *Proceedings - IEEE Military Communications Conference MILCOM*, pp. 982–987, 2016, doi: 10.1109/MILCOM.2016.7795458.

[21] R. Sarno, F. Sinaga, and K. R. Sungkono, "Anomaly detection in business processes using process mining and fuzzy association rule learning," *Journal of Big Data*, vol. 7, no. 1, pp. 1–19, 2020, doi: 10.1186/s40537-019-0277-1.

[22] T. Xiong, M. Pan, Y. Yu, and D. Lou, "Detecting Data Flow Errors Across Processes in Business Process Collaboration," *IEEE Access*, vol. 8, pp. 170862–170871, 2020, doi: 10.1109/access.2020.3024689.

[23] P. Weber, B. Bordbar, P. Tino, and B. Majeed, "A framework for comparing process mining algorithms," *2011 IEEE GCC Conference and Exhibition, GCC 2011*, no. February, pp. 625–628, 2011, doi: 10.1109/IEEEGCC.2011.5752616.

[24] R. Ghawi, "Process Discovery using Inductive Miner and Decomposition," no. November, 2016, [Online]. Available: http://arxiv.org/abs/1610.07989.

[25] A. J. M. M. Weijters, W. M. P. van der Aalst, and A. K. A. de Medeiros;, "Process Mining with the Heuristics Miner Algorithm," *Beta working papers*, no. January 2006, 2006.

[26] R. Sarno, P. L. I. Sari, D. Sunaryono, B. Amaliah, and I. Mukhlash, "Mining decision to discover the relation of rules among decision points in a non-free choice construct," *Proceedings of 2014 International Conference on Information, Communication Technology and System, ICTS 2014*, pp. 53–57, 2014, doi: 10.1109/ICTS.2014.7010557.