Integrated Railway Timetable Scheduling Optimization Model and Rescheduling Recovery Optimization Model: A Systematic Literature Review

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Abstract—**Research study in the railway optimization can be divided into strategic, tactical and operational area. In this paper, we will focus on discussing railway scheduling optimization and rescheduling recovery technique which (tactical and operational area) because these topics are usually complex and in the real case train is often delay from a predetermined schedule. We use Systematic Literate Review (SLR) to reviewing selected journals and articles which related with our research focus. The output of this Systematic Literature Review is possibility opportunity study in the railway scheduling and rescheduling recovery technique optimization. We also proposed an enhanced no-wait blocking parallel-machine job-shop-scheduling model optimization on railway scheduling and rescheduling recovery technique for our next research. The proposed model will consider new variable about rail line balancing using drum buffer rope, one of theory of constrained, and integrated with number of passenger car composition number and track backup rescheduling in partial double track rail line.**

Keywords-railway optimization; railway timetable scheduling; railway rescheduling recovery technique; job shop scheduling

I. INTRODUCTION

In research in the field of optimization, railway optimization has become a trend in recent studies. That's because all countries in the world are developing and improving the rail system which is one of the land transportation. In the world of supply chain and logistics, railway plays an important role in the distribution of goods, because in addition to having a relatively short travel time, trains also have a low cost in travel. Because of some of the advantages of the train, people also choose the train as a mode of transportation daily.

Research on railway optimization is divided into three areas of study, i.e., strategic planning, tactical planning and operational planning [1]. At the strategic level, which is the long-term design level, the optimization assessment is more toward meeting the demand of passengers who will use the rail services. At the tactical level, the design is done in a relatively faster time, i.e., in a matter of years. Designing at this level is particularly suitable for countries that are building and developing an existing railway system in an area, such as, partial railway development. The last railway design level is the operational level. At this level the optimization design is carried out is to supervise the current railway system.

Research which often studied in the railway in tactical and operational level, especially in railway scheduling and rescheduling, is how to minimize the total cost of high travel train cost so as to increase profit from the company [2]. One reason for the high cost of rail travel is un-optimal amount of passenger car composition in a series of trains, thus causing passenger car is not filled by passengers. This event is called a deadhead trip [3]. This condition will lead to high operational costs. Fundamentally, the operational cost is divided into two, that is, the cost of the locomotives in generating energy to attract the range of trains and the costs required of generating wagons to generate electricity used to power electronic train equipment, such as train chillers, lights, TVs and others [4]. Both components of the cost will increase linearly in line with the increasing number of compositions of the passenger car on a train series.

This literature review aims to identify and analyze research trends, methods and variables which used to minimize total cost of railway operation in tactical and operation area. Methodology for this literature review will be explained in Section II, and Section III will explain the research about future optimization model and we will propose a new model to improve railway scheduling and rescheduling, but it still a concept and the model will be verified in our next research in Section IV. In the last section, we will give the summary about this systematic literature review, containing possibility research in railway rescheduling.

II. METHODOLOGY

A. Systematic Literature Review Overview

Systematic literature review is chosen for reviewing the way to minimize total train operation cost. Systematic literature reviews are used to assess referenced journals systematically and objectively. The aim is to minimize the bias associated with single studies and non-systematic reviews [5]. The aim of systematic literature review is tightly specified with the research topics and objectives with a specific review questions, while the aim of traditional literature review is to gain broad understanding and give descriptions about the research topics. The scope of

systematic literature review is narrow focus, deeply discussing the research topic.

B. Research Questions (Mapping Scope Review)

The process for reviewing the literature depends on the predefined research question. This is one of the characteristics of the systematic literature review. In order to write the systematic literature of this review, the teacher compiles the research questions in Table I.

TABLE I.   RESEARCH QUESTIONS

ID	Research Question	Purpose
Q1	Which journal is the most significant in reviewing optimal model of railway scheduling?	Identify the most significant journal which reviewing optimal model of railway scheduling and rescheduling.
Q2	What kind of research topics which are often discussed in the way to mitigating total train travel cost?	Identify the research trends in how to minimize total train travel cost.
Q3	What type of scheduling algorithm which most discussed in the previous research?	Identify the of scheduling algorithm which most discussed in the previous research.
Q4	What variables are most discussed to minimize operation in train travel?	Identify the variables which are most causes high operation cost in train travel.
Q5	What kind of variables which must be considered for the next research to mitigating total train travel cost?	Identify variables consideration for future research to mitigating total train travel cost.

C. Comprehensive Search

Before doing a search, we determine several sources of journal publishers relating to the research to be conducted. This step is used to make it easier to search for the appropriate journal. Here is the list of digital publishers:
- Taylor & Francis (http://www.tandfonline.com)
- ScienceDirect (http://www.sciencedirect.com/)
- IEEE Explore (http://ieeexplore.ieee.org/)
- Springer (https://link.springer.com/)

D. Study Selection (Quality Assessment)

To perform the relevant recapitulation of the literature, we use the help of *mendeley* software *(https://www.mendeley.com)*. In addition to recapitulating the literature, *mendeley* is also petrified in doing reference writing.

TABLE II.   SELECTION CRITERIA

Accepted Criteria	Scheduling for parallel identic machine.
	Scheduling optimization for railway in partial double track railway line.
	Optimal model in railway timetable planning.
	Scheduling under shunt process for changing passenger car composition.
	Rescheduling using track back up recovery.
Rejected Criteria	Scheduling optimization under maintenance consideration.
	Railway signaling optimization.
	Studies not written in English.

After we took the step of study selection using Table II, we found 26 journals that fit our study.

III. RESULT

A. Significant Journals Publication

Researchers continue to innovate and to create optimization of railway scheduling and rescheduling because of the high interest of the people, used train as a transportation mode, causing the density of rail traffic. Its proved by the number of related journal being increased since 2008 until 2017 (see Figure 1). It indicates that railway scheduling optimization and rescheduling recovery technique research has become an important study in recent years.
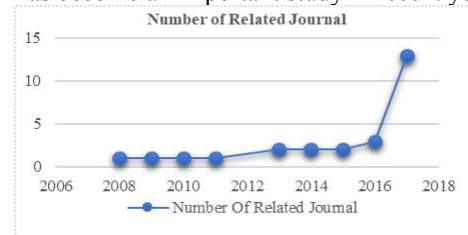

Figure 1.   Number of related journal.

The related journal which used as the references to write this systematic literature review comes from fifteen publication journals (Figure 2). Railway timetable scheduling are mostly obtained from Transportation Research Publication Journal in Part B: Methodological and Part C: Emerging Technologies. Conference proceedings are not included in this graph.
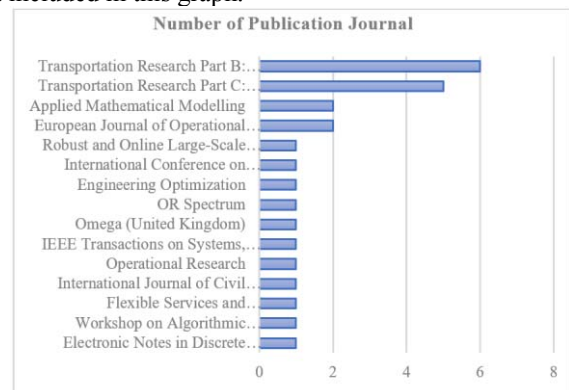

Figure 2.   Number of publication journal.

B. Research Topics in Railway Scheduling

There are two kind of research topics in railway scheduling as seen on Table III. **First,** research topic about scheduling the train timetable. The basic objective functions about train scheduling are to minimize total travel duration and minimize the deviation between actual time with the original scheduled timetable. **Second,** research topic about railway rescheduling recovery technique. To keep the robustness of railway scheduling when some delay occurs, it needs some recovery techniques. Type of recovery technique depend on the real-time case. If the disruption occur with small recovery time, it only need basic rescheduling

technique, usually, changing train sequence and decrease loading time in the station. But if disruption happen with high recovery time, special technique must be applied to restore the robustness of the origin optimal scheduling time table.

TABLE III.   MAPPING REFERENCED JOURNAL TO THE RESEARCH TOPIC

No.	Referenced Journal	Type of Research Topics	
		Scheduling	Rescheduling
1.	[6]	v	
2.	[7]	v	
3.	[8]	v	
4.	[4]	v	
5.	[1]	v	
6.	[3]	v	
7.	[9]	v	
8.	[10]		v
9.	[11]		v
10.	[12]		v
11.	[13]		v
12.	[14]		v
13.	[15]		v
14.	[16]		v
15.	[17]		v
16.	[18]		v
17.	[19]		v
18.	[20]		v
19.	[21]		v
20.	[22]		v

C. Most Discussed Scheduling Algortihm

Basically, railway time table scheduling can be solved by two kinds of algorithm, job shop scheduling and flow shop scheduling. Liu [23], classify scheduling job shop scheduling and flow shop scheduling into several algorithm classifications: (a) Blocking Constrain Flow Shop Scheduling; (b) No-wait Flow Shop Scheduling; (c) Combined-buffer Flow Shop Scheduling; (d) Blocking Constrain Parallel Machine Flow Shop Scheduling; (e) No-wait Parallel Machine Flow Shop Scheduling; (f) No-wait Blocking Constrain Parallel Machine Flow Shop Scheduling; (g) Parallel-machine Job Shop Scheduling; (h) Limited-buffer Flow Shop Scheduling;   (i) Blocking Constrain Job Shop Scheduling; (j) Blocking Constrain Parallel Machine Job Shop Scheduling; (k) No-wait Parallel Machine Job Shop Scheduling; (l) No-wait Blocking Constrain Parallel Machine Job Shop Scheduling

D. Most Discussed Variables in Railway Scheduling

To recap most discussed decision variables, we categorize decision variable into three general categories, i.e., type of rail track, railway scheduling decision variable, and railway rescheduling variable.

1. Type of Track
The type of railway line plays the most important role in determining railway scheduling optimization model. Partial double track is the type of railway that has the highest difficulty in scheduling or rescheduling recovery. If the developed model is not optimal, there will be bottleneck in several segment blocks because each segment block has different processing capacity time. The most frequently used

case study in some studies is the complete double-track rail line (see Figure 3). Double track line has each function to process the train in bidirectional. Besides, double track line used double track line is used to back up each other if one rail cannot be passed because of line blockage occurs.
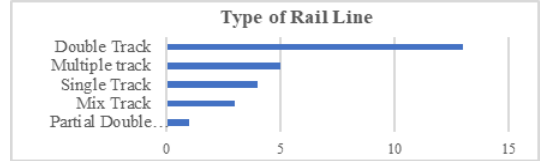

Figure 3.   Number of journal based on type of rail Line.

2. Scheduling Decision Variables
Basic scheduling concept is arranging train dispatching from origin departure station to minimize delay caused by train crossing in the middle trip. This decision variables are integrated together so it is reasonable that a study uses several decision variables to create optimal railway scheduling model.

In railway scheduling decision variables, we categorized this decision variable into two, delay decision variables (marked as blue rectangle) and operation decisions variable (marked as orange rectangle). The most discussed decision variable in delay category is delay frequency in station and in operation category is total travel duration (see Figure 4).
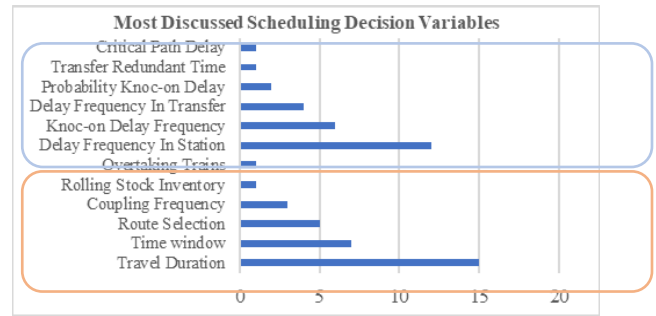

Figure 4.   Number of journal based on scheduling decision variable.

E. Possibility Proposed Research for Railway Scheduling

1. Gaps Found
After we studies the referenced journals and other literature, we found some gaps which not be considered in the previous research. The main gaps about railway scheduling optimization are listed in the topics below:

- In the previous study, there was no literature review focusing on railway timetable scheduling optimization and rescheduling recovery technique optimization.
- From the referenced journal, we found no research on railway timetable scheduling that takes into account the rail capacity of a block segment.
- We only found one journal that integrates the basic railway timetable scheduling with rescheduling recovery optimization [16]. Rescheduling is needed to keep scheduling robustness in case of disruption in case of line blockage.

2. Next Research Opportunities
The main gaps that have been described, several research opportunities that can be reviewed in the next research about

railway scheduling timetable are listed bellows:

a) Integrated scheduling optimization with new variable consideration (multi-criteria).
b) Integrated scheduling optimization with multi-objective model.
c) Railway scheduling consider rail capacity to mitigate bottleneck during the trip.
d) Railway scheduling consider recovery technique in a complex rail network.
e) Railway scheduling consider train priority and overtake the lower priority train.

IV. INTEGRATED MODEL IN RAILWAY SCHEDULING

The solution of railway scheduling optimization problem is highly dependent on the problem as a case study in a study. One of the key parameters in making a railway scheduling optimization model is the rail type of the rail system. Basically, we used previous scheduling model research from [3]. This model used to manage passenger car composition in a train series which can minimized total train travel cost. The disadvantages scheduling model from [3] is not suitable if implemented with study case in Indonesian Railway Company.

First, the previous model does not consider type of railway line. Indonesian railway has partial double track railway line. This type of railway line need special optimization model to avoid bottleneck while switching from double track line to single track line and otherwise. In theory of production, bottleneck happens caused by unbalance processing capacity [24]. Using this scheduling theory, bottleneck in transition between double track to single track railway line and otherwise, happened because double track line has larger capacity processing time in comparison single track railway line. Besides, bottleneck not only happened in transition between double track to single track railway line, but also happened in the same rail directions caused by different processing time between each rail segment. Second, most scheduling journal does not consider basic rescheduling model if disruption happen in the rail line. Rescheduling recovery technique only discussed in railway rescheduling journal which used special recovery technique.

As the output of this systematic literature review, we propose an optimized scheduling optimization model with basic rescheduling model to handle in case of disruption in the railway line, which describe in Section 4. Our proposed optimization model considers some integrated variable, i.e.:

1. Utilization of capacity processing time in each rail segments, especially in transition between double track to single track rail line. We will used drum buffer rope algorithm to handle these processes. Drum buffer rope is one of theory of constrain method [25].
2. Number of passenger car composition in a train series. We also consider this variable because deadhead trip will cause high operation cost. The tradeoff of this optimization is there will be an extra time delay in some station to do shunting to coupling or uncoupling the passenger car.
3. We add the basic rescheduling model into our proposed model. We used model from [16] to recover railway scheduling if there are any disruption in case mixed blockage rail line.

A. Objective Function

Our proposed model used no-wait blocking parallel-machine job-shop-scheduling, combines tree objective function, i.e., (a) basic scheduling model with has objective to minimize total traveling time consider rail capacity processing time, (b) scheduling model consider shunting operation to change the optimal composition of passenger car in a train series and (c) rescheduling model in partial double track using track backup rescheduling recovery technique.

In basic scheduling model, we consider new variable to control the balancing of rail capacity to process the train, called drum buffer rope.
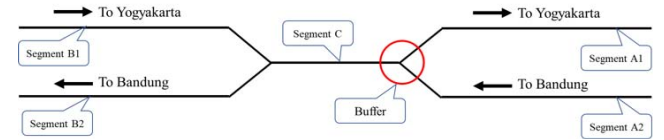

Figure 5. Drum Buffer Rope Illustration

In Figure 5, rail segment C have smaller capacity processing time than segment A and B. Drum buffer rope (once of Theory of Constrain) used to give additional constrains to limit the larger capacity processing time.

$$min = \left[\sum_{s \in S} \sigma_s^{time}(e_s^A - e_s^D) \right] \tag{1}$$

$$min = \sum_{s \in S} \left[c_s^{time} t_s^{total} + c_s^{dev} t_s^{dev} + \sum_{w \in W} f_w^{split} c_w^{split} \right] \tag{2}$$

$$min = \left[\sum_{s \in S} \sigma_{sj}^D(a_{sj}^{act} - a_{sj}^{plan}) \right] + \left[\sum_{s \in S} \sum_{j \in J} \sigma_{sj}^L |b_{sj}^{act} - b_{sj}^{plant}| \right] \tag{3}$$

We use tree objectives function. Equation (1) is basic railway scheduling to minimize total travel time. Equation (2) is railway scheduling consider shunting operation to change the number of passenger car composition in a train series. Equation (3) is rescheduling model from [16] which has nonlinear function. If the train is late or too quickly departed or dispatched from a station, it will be penalized.

B. Constrains

1. Basic Railway System Constrains

Minimal safety constrains between train

To keep a safe distance between trains in entering a same station will be limited by the delimiter functions (4) and (5). The distance between train arrivals at a station must be greater than or equal to the travel time in the block segment before the station.

$$b_{j(s+1)} - a_{js} \geq t_{js} \tag{4}$$

$$b_{js} - a_{j(s+1)} \geq t_{js} \tag{5}$$

Headway minimum in a block segment

$$d_{js} - h_s \geq d_{ks} \tag{6}$$

$$b_{ij} \geq \hat{a}_{ij} \tag{7}$$

The speed of the train we assume has a uniform distribution. Equation (6) and (7) are constrains function to limit the minimum and maximum speed of trains in each block segment, since each block segment has a heterogeneous speed limiter.

Rail Network Balancing

$$s_{k,j} \geq \int_{-h}^{0} \int_{0}^{h+1} h_{sk} \geq d_{jk} \qquad (8)$$

Equation (8) is a drum buffer rope constrain which used to limit the train speed at segment k. With this limiting function, the train will run slower than the upper limit of processing time capacity on a segment that has greater processing time than others. The train should not run faster than the additional drum buffer rope constrains although it has not reached the maximum speed limit of the block segment. However, the train also should not run too slowly from the allowance given to the model because it will cause long delays and travel time.

2. Railway Rescheduling Constrain

Constrain used in this proposed model is adapted from previous research, see [16] for the complete constrains model which will be modified by us in the next research. The concept of railway rescheduling constrain are: (a) limit the number of track; (b) if the disruption happens in partial blockage rail line, train will be scheduled into the other parallel segment which not blocked by disruption; (c) if the disruption happens in single track segment train will search nearest station to wait the disruption; (d) train will be canceled if the disruption need long time to be fixed.

V. CONCLUSION

In the result of this Systematic Literature Review, the topic that becomes an opportunity to be studied in railway scheduling and rescheduling study area is consider other variables that have not been considered in previous research and do integration of objective function (multi-objective). We also found that scheduling and rescheduling on partial double track rail line are still rarely discussed due to the high level of complexity. Therefore, our next study is to investigate the integrated model of railway scheduling and rescheduling consider heterogeneous rail track capacity and optimal composition of passenger car in a train series. At the end of this section in this Systematic Literature Review, we present a rough model under the proposed study in our next research but not yet been validated and verified.

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