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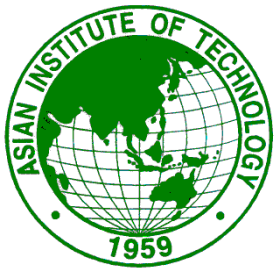
Edited by

Voratas Kachitvichyanukul
Huynh Trung Luong
Rapeepun Pitakaso



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Shift Pattern in Cyclic Scheduling with Between-Days Break-Time Constraint

Deny Ratna Yuniartha†
Department of Industrial Engineering, Faculty of Industrial Technology
Universitas Atma Jaya Yogyakarta, Indonesia
Tel: (+62) 0274-487711Fax: (+62) 0274-485223
Email: dena@mail.uajy.ac.id

Abstract. This article is concerned with shift scheduling problem for front office staffs. The front office operates for 24 hours in 3 shifts (morning, evening, night) and served by 3 staffs. Each staff will be assigned in three different shift each day. Since the number of staffs equal to the number of shifts then the problem arises in determining the shift pattern assigned to staff in one cycle period. The shift pattern must consider day-off assignment in one cycle period that prevent staff shortage, and satisfy minimum duration of between-days break-time to prevent the staff experiences fatigue. We determine optimal cycle period that distribute each shift type in average among 3 staffs, then we develop shift pattern by assigning off-day and shift types in one cycle period. We establish that the developed schedule satisfy all the constraints.

Keywords: shift scheduling, cyclic scheduling, shift pattern, between-days break-time

1. INTRODUCTION

YAKKUM Emergency Unit (YEU) is one of departments own by Yayasan Kesehatan Kristen Untuk Umum (YAKKUM), a Christian foundation in health sector whose headquarter in Surakarta, Central Java. YEU was founded in 2001 and has been active in disaster response with the principles of neutrality and impartiality. YEU has conducted disaster response in some areas in Indonesia and neighboring countries with no regard to race, religion, or a particular group, but emphasize in humanity to help disaster victims. In 2008, YEU built a disaster learning facility called Disaster Oasis Training Center. Disaster Oasis Training Center offers services of disaster learning in form of disaster preparedness training packages and hostelry, equipped with disaster information in form of photo, documentary film and books available in library, and variation of visual aid. The hostelry facilities offered are the model of post-disaster houses or buildings built in areas whose assisted by YEU.

As a newly hostelry, Disaster Oasis Training Center faces problems, and one of which is the cyclic shift pattern for Front Office staffs roster. The shift pattern is not effectively viewed by management, because of the short between-days break-time, 8 hours between days for 3 consecutive days. Between-days break-time is duration from end of shift in certain work day and start of shift for next work day, assigned to a staff. The short between-days break-time results in staff frequently come late in morning shift at 7 a.m. because in the previous day he has been assigned in evening shift finished at 11 a.m.

The Front Office of Disaster Oasis Training Center operates 24 hours divided into 3 shifts, i.e. morning shift (M) from 7 a.m. to 3 a.m., evening shift (E) from 3 a.m. to 11 a.m., and night shift (N) from 11 a.m. to 7 a.m. The Front Office has 3 staffs and each of shift should be serve by 1 staff. Because the number of staffs equal to the number of shifts and each of staff should have one-day-off once a week, then there will be overtime to overcome staff shortage. It means that one staff will be assigned in 2 consecutive shift in one day when there is 1 other staff assigned to one-day-off. The first shift assigned will be considered as regular time and the second shift as overtime.

Front Office applies cyclic shift scheduling in which 1 cycle period consists of 5 consecutive work days (work stretch) following by one-day-off. The shift pattern assigned in work days is N-N-E-ME-M. This shift pattern means that a staff will come in night shift in first day and second day, evening shift in the third day, morning shift following by evening shift in the fourth day, and morning shift in the fifth day. After that, the staff will have one-day-off then repeating the cycle. Table 1 shows cut of the cyclic

† : Corresponding Author

shift scheduling applied.

Table 1: Cut of the shift scheduling applied

Staff	Date					
	1	2	3	4	5	6
A	N	N	E	ME	M	O
B	E	ME	M	O	N	N
C	M	O	N	N	E	ME

The first column in Table 1 shows the staff name and the second until sixth column show the shift assigned to each staff for each day (shown in date). The alphabet in each cell show the shift assigned to each staff each day. "M" refers to morning shift, "E" for evening shift, "N" for night shift, and "O" for one-day-off. The shift pattern in 1 cycle period will be applied overlapping among 3 staffs, so that when 1 staff has one-day-off then 2 other staffs will be on duty, i.e. 1 staff assigned for 1 shift and the other staff assigned for 2 others consecutive shifts. Staff A in Table 1 starts on 1st date with the 1st day of the cycle (shift N), but staff B starts with the 3rd day of the cycle and staff C with the 5th day of the cycle. This overlapping condition is applied in order to ensure that there will be no staff shortage when 1 staff has one-day-off. Staff C has one-day-off on date 3, so that in the same day staff A is assigned in shift N and staff B is assigned in shift M continued in shift E. The shift E assigned to staff B is considered as overtime.

This cyclic shift pattern results in short between-days break-time, 8 hours between days, i.e. from shift N to shift E next day and form shift E to shift M next day. Table 1 shows that staff A is assigned in shift N on date 2 which will finish at 7 a.m. next day, i.e. date 3. Staff A on date 3 is assigned in shift E start at 3 a.m., consequently staff A just has 8 hours for break, i.e. from 7 a.m. until 3 p.m. This condition is repeated for date 3 to date 4 and also for date 4 to date5 (from shift E to M). As a result, staff will be late to come in shift M at 7 a.m. because in the previous day he has been assigned in shift E finished at 11 p.m. Moreover, managements view that this cyclic shift pattern will give indirectly influence to staff performance because for 3 consecutive days staff just has 8 hours leisure time for rest, family, and social activities.

For the problem addressed in this article, the major concern is to determine cyclic shift pattern that give adequate between-days break-time for Front Office staffs to have leisure time for rest, family, and social activities. Minimum between-days break-time is considered based on remaining time of 1 day (24 hours) after a staff is on duty for 1 shift. The management will regulate new shift time arrangement, i.e. morning shift (M) from 8 a.m. to 4 a.m., evening shift (E) from 4 a.m. to 11 a.m., and night shift (N) from 11 a.m. to 8 a.m. The longest shift duration is the shift N, i.e. for 9 hours, so minimum between-days break-time that could be given to a staff is 15 hours. The number of staff is remain constant (3 staffs) during a month and staffs are not allowed to select a certain day for one-day-off. The shift pattern is arranged in cyclic period that evenly distribute each shift type among all staffs, and should be easy to remember for staffs.

The remainder of this paper is organized as follows. Section 2 describes the relevant literatures on shift scheduling and cyclic scheduling. In section 3, we describe the solution method in detail and the result. Finally, section 4 presents conclusions and some suggestions for future research.

2. LITERATURE REVIEW

Workforce scheduling problem classified into 3 categories, i.e. (1) day-off scheduling, (2) shift scheduling, and (3) tour scheduling, which combine simultaneously day-off and shift scheduling. Scheduling problem addressed in this article focus on tour scheduling, that is develop cyclic shift pattern for staff rostering in which also considering day-off assignment in the pattern and between-days break-time constraint. The major concern is to determine the work stretch length, one-day-off assignment, and shift assignment in work days. The developed work stretch length, day-off assignment, and shift pattern should be in cyclic manner and prevent workforce shortage. Elshafei and Alfares (2008) has conducted research in day-off assignment to minimize labor cost using dynamic programming algorithm. Elshafei and Alfares (2008) has considered work-stretch-length, maximum number of word-day and off-day in a week, and work-sequence-dependent cost structure as a constraint, but has not considered multi-shift application yet.

Some of researches in shift scheduling have been done by Bard and Wan (2005), Burke *et al.* (2006), Bhulai *et al*. (2008), and (Rekik *et al*. 2010). Bard and Wan (2005) has proposed algorithm for weekly scheduling in service industry which has full-time and part-time employees. The developed algorithm overcomes workforce shortage due to high workforce requirement by applying overtime, increasing number of part-time hours, and calling in casual workers. The resulting shift scheduling provides daily assignments for each worker only for 1 week based on weekly demand requirement. Burke *et al*. (2006) also provides daily assignment in shift scheduling. It is for nurse rostering to handle personnel requirement in term of time interval, that is the representation of the personnel requirements per day in terms of the start and end times of personnel attendance. Shift type combinations that fulfill the personnel requirements is developed by split or combine the shifts. Bhulai *et al*. (2008) have also proposed

daily assignment in shift scheduling which considering multi-skill workers. The proposed method consists of 2 steps, staffing level and shift scheduling. Staffing level translate the amount of workload into number of required workers. Shift scheduling then uses such that staffing level to assign worker in pairing of shift into a rosters.

For considering shift flexibility, Rekik *et al*. (2010) have developed a model of shift scheduling problem that includes different forms of flexibility in terms of shift starting times, break lengths, and break placement in order to determine total workforce size. Other researches in shift flexibility have been done by Rekik *et al*. (2004), Addou and Soumis (2007), Brunner *et al*. (2009), and Brunner *et al*. (2011). In contrast to Rekik *et al*. (2010), these researches have considered the day-off scheduling. Rekik *et al*. (2004) and Addou and Soumis (2007) focus on minimizing total labor cost of all shifts to determine total workforce size. Brunner *et al*. (2009) and Brunner *et al*. (2011) also focus on minimizing labor cost but not in rostering problem, that is personnel assignment under the restrictions by regulation or individual preferences.

Litchfield *et al*. (2003) and Kaluzny and Hill (2011) have provided rostering regarding shift scheduling and day-off assignment. Day-off assignment in Litchfield *et al*. (2003) considers constraints of staffing requirement, employees avaibility, maximum and minimum number of shift per week, and employee experience requirement per period. While Kaluzny (2011) assigns security personnel in cyclic six days work pattern base on required number of personnel each day. The shift in cyclic six day pattern is previously determined. The resulting roster in Litchfield *et al*. (2003) and Kaluzny and Hill (2011) is only for 1 planning period and it may vary for other period by the personnel requirement. Whereas the same work pattern may repeat each n periods, called cyclic scheduling. Cyclic scheduling may apply in day-off scheduling, shift scheduling, or tour scheduling. Alfares (2001) have proposed a method in cyclic day-off scheduling. The objective of the proposed model in Alfares (2001) is minimizing number of worker in 7 work days with 2 consecutive day-off. While for cyclic shift scheduling, Maenhout and Vanhoucke (2009) have proposed algorithm in rostering problem considering specific characteristics of personnel. The considered employee characteristics are cyclical roster type, degree of employment, skill categories, and general preferences. Cyclical roster type is previously predetermined shift and day-off assignment in a week. And there are 2 types of cyclical roster type.

Cyclic tour scheduling problem has been investigated in Carter and Lapierre (2001), Felici and Gentile (2004), Laporte and Pesant (2004), Bard and Purnomo (2007), and (Lezaun *et al*. 2010). These researches have proposed algorithm to assign work day and off-day in evenly distribution among personnel. The number of consecutive work day or cycle length of these researches, except in Felici and Gentile (2004), is considered as parameter or constraint, not as solution. Carter and Lapierre (2001) and Bard and Purnomo (2007) explicitly use certain amount hours of break time as constraint for consecutive shifts. Felici and Gentile (2004), Laporte and Pesant (2004), and Lezaun *et al*. (2010) use shift change pattern as break constraint.

3. SOLUTION METHOD

The solution method for solving the problem is done in 4 steps, i.e.:

1. Determination of work stretch in 1 cycle period
2. Determination of overtime pattern in 1 cycle period
3. Determination of shift pattern in 1 cycle period
4. Determination of shift pattern in 1 cycle period that satisfy between-days break-time constraint

Description of each step is presented as follows.

3.1 Determination of Work Stretch in One Cycle Period

One cycle period of scheduling for Front Office staff rostering consists of consecutive work days (work stretch) and ended by one-day-off. Length of the work stretch in 1 cycle period should consider several factors, i.e. 24 hour operational time that divided into 3 shift, number of staff available, number of work days that must be fulfilled by a staff, and the right of a staff to have one-day-off once a week. Number of staff equals to number of shift type, and each of shift must be served by a staff, so that there will be staff shortage when a staff have one-day-off. Average number of work days in a month is 30 days, means that there will be 90 shifts in a month that should be assigned (30 days/month x 3 shifts/day). Meanwhile a staff should be assigned just for 1 shift in a day and have one-day-off once a week, so that a staff just could be assigned for 26 shifts in a month, assume there is 4 weeks in a month. The Front Office has 3 staffs so that number of shift that could be served just for 78 shifts in a month (3 staffs x 26 shifts/staff/month). Consequently there will be 12 shifts in a month that should be assigned to staffs as overtime. This overtime shifts should be evenly distributed among all staffs.

Number of shift type should be evenly distributed to all staffs. It means that there are 5 condition that should be distributed to all staff, i.e. 3 shift types (M, E, N), overtime shift (O), and one-day-off (H). One cycle period consists of combination of that 5 conditions. And the 5 conditions should be evenly distributed in 1 month (30 days) so that the length of 1 cycle period is 6 days (30 days divided by 5

conditions/cycle). In 1 cycle period, there will be 5 work days and one-day-off, and the condition assigned to work days is the combination of M, E, N, and O. One day off is assigned on the 6th day in order to mark out the end of 1 cycle period. Table 2 shows the 1 cycle period.

Table 2: Work stretch and off-day in 1 cycle period

1 Cycle Period					
1st day	2nd day	3rd day	4th day	5th day	6th day
On duty	On duty	On duty	On duty	On duty	off

3.2 Determination of Overtime Pattern in One Cycle Period

In order to guarantee no staff shortage as a result of one-day-off that should be assigned to staff once a week, then the 1 cycle period will be assigned overlapping among 3 staffs. Each staff is assigned to have one-day-off in 1 cycle period, consequently in 6 days length of the applied overlapping cycle period there will be 3 times one-day-off for 3 staff, means that there will be one-day-off every 2 days. Thereby, arrangement of shift type in work stretch of 1 cycle period should be consider that every 2 days there is 1 staff assigned to one-day-off and at the same time there is 1 staff assigned to have overtime. Because overtime is to overcome one-day-off so that overtime should be also at a distance of 2 days in 1 cycle period. One-day-off in 1 cycle period is assigned in the 6th day as the mark of end cycle, so that the overtime is assigned in 2 days before one-day-off, i.e. in the 4th day. Table 3 shows one-day-off and overtime assigned in overlapping cycle period among 3 staffs.

Table 3: One-day-off and overtime pattern in 1 cycle period

Staff	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
A	On duty	On duty	On duty	Overtime	On duty	Off
B	On duty	Off	On duty	On duty	On duty	Overtime
C	On duty	Overtime	On duty	Off	On duty	On duty

Overtime is assigned to a staff due to other staff has one-day-off, so as to make it easier, overtime pattern is applied by assigned 2 consecutive shifts in one day to a staff. Then there will be 2 possibilities pattern, i.e. morning shift followed by evening shift (ME) and evening shift followed by night shift (EN). Nigh shift followed by morning shift (NM) could not be applied because the morning shift is constitute to next day. For ME pattern, if there is 1 staff assigned to have one-day-off then 1 staff is assigned on morning shift followed by evening shift, that is 1 shift considered as regular time and other shift considered as overtime, and the other staff is assigned in night shift. So it is for EN pattern.

Overtime and one-day-off should be at a distance of 2 days in 1 cycle period, so as to make the cycle period overlapping among 3 staffs, the shift assigned on 2 days before overtime should be different from the shift type for the overtime. It means that the 2nd day in 1 cycle period should have different shift type with overtime on the 4th day. For overtime shift pattern ME, the shift pattern on 2nd day in 1 cycle period is N. Whereas the shift pattern on 2nd day in 1 cycle period is M for overtime shift pattern EN. Table 4 and Table 5 show the possibilities shift pattern for overtime in 1 cycle period.

Table 4: Overtime shift pattern ME

Staff	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
A	On duty	N	On duty	ME	On duty	Off
B	On duty	Off	On duty	N	On duty	ME
C	On duty	ME	On duty	Off	On duty	N

Table 5: Overtime shift pattern ME

Staff	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
A	On duty	M	On duty	EN	On duty	Off
B	On duty	Off	On duty	M	On duty	EN
C	On duty	EN	On duty	Off	On duty	M

3.3 Determination of Shift Pattern in One Cycle Period

The next step is to determine the shift pattern for work stretch in 1 cycle period besides the overtime day and one-day-off, i.e. the 1st, 3rd, and 5th day in the work stretch. For 1 cycle period of 6 days-long, a staff should be assigned for 6 shift, 5 shifts as regular time and 1 shift as overtime. There are 3 types of shift (M, E, and N) and each of this type should be evenly distributed in 1 cycle period, so that each shift type will be assigned twice in 1 cycle period. The overtime shift has assigned for 2 types (ME or EN) and it is distinct with shift assigned on the 2nd day (N for ME, or M for EN), so that for each shift type we just need to assign once for the 1st, 3rd, and 5th day in the work stretch. There are 3 types of shift that should be assigned then there are 6 alternatives of shift combinations, showed in Table 6. There are 2 alternatives of shift pattern for overtime consequently there are 12 alternatives of shift pattern for work days in 1 cycle period, showed in Table 7.

Table 6: Alternatives of shift combination for 1st day, 3rd day, and 5th day in 1 cycle period

Alternatives	1st day	3rd day	5th day
1	M	E	N
2	M	N	E
3	E	N	M
4	E	M	N
5	N	M	E
6	N	E	M

3.4 Determination of Shift Pattern in One Cycle Period That Satisfy Between-Days Break-Time Constraint

In this step, we will analyze the 12 alternatives shift pattern in 1 cycle period by means of considering minimum between-days break-time, i.e. 15 hours. For overtime shift pattern ME, we can not assign shift M to the 5th day in 1 cycle period because it will result in 9 hour between-days break-time. So we just could assign shift E or N at the 5th day. If we assign shift E at the 5th day then for the 1st and 3rd day are combination of shift M and N, and then we will have combination of shift M and E for the 1st and 3rd day if we assign shift N to the 5th day. So that overtime shift pattern ME will result in 4 alternatives shift pattern for 1 cycle period. The shift assignment at the 5th day that satisfy minimum between-day break-time for shift pattern EN is shift N. This assignment will result in combination of shift M and E for assignment at the 1st and 3rd day. So that overtime shift pattern EN will result in 2 alternatives, and as a result we reduce the 12 alternatives shift pattern in 1 cycle period become 6 alternatives, showed in Table 7.

Table 7: Alternatives of shift pattern for 1 cycle period

Alternatives		1 Cycle Period					
No	Overtime	1st day	2nd day	3rd day	4th day	5th day	6th day
1	ME	N	N	M	ME	E	O
2		M	N	N	ME	E	O
3		M	N	E	ME	N	O
4		E	N	M	ME	N	O
5	EN	M	M	E	EN	N	O
6		E	M	M	EN	N	O

For the alternatives in Table 7, we will provide further analysis the between-days break-time duration for other days besides the 5th day. Table 8 shows the between-days break-time duration for shift pattern that currently applied, Table 9 to Table 14 show the between-days break-time duration for each alternatives. The shading cell shows the assigned shift in the day of column header. The hour written in the shading cell shows the between-days break time duration, determined form the end shift of previous work day until the start shift of the work day in column header. Table 15 shows minimum, maximum, and standard deviation of between-days break-time duration for each alternative.

Table 8: Between-day break-time for shift pattern currently applied (N-N-E-ME-M-Off)

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M				8 h	8 h	Off
E			8 h			
N	56 h	16 h				

Table 9: Between-day break-time for alternatives shift pattern N-N-M-ME-E-Off

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M			0 h	16 h		Off
E					17 h	
N	48 h	15 h				

Table 10: Between-day break-time for alternative shift pattern M-N-N-ME-E-Off

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M	33 h			0h		Off
E					17 h	
N		31 h	15 h			

Table 11: Between-day break-time for alternative shift pattern M-N-E-ME-N-Off

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M	24 h			9 h		Off
E			8 h			
N		31 h			24 h	

Table 12: Between-day break-time for alternative shift pattern E-N-M-ME-N-Off

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M			0 h	16 h		Off
E	32 h					
N		24 h			24 h	

Table 13: Between-day break-time for alternative shift pattern M-M-E-EN-N-Off

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M	24 h	16 h				Off
E			24 h	17 h		
N					15 h	

Table 14: Between-day break-time for alternative shift pattern E-M-M-EN-N-Off

Shift	1 Cycle Period					
	1st day	2nd day	3rd day	4th day	5th day	6th day
M		9 h	16 h			Off
E	32 h			24 h		
N					15 h	

Table 15: Between-days break-time duration for 6 alternatives

Alternative		Between-Days Break-Time Duration		
No	Shift Pattern	Min	Max	Standard Deviation
1	N-N-M-ME-E-Off	0	48	15.69
2	M-N-N-ME-E-Off	0	33	12.01
3	M-N-E-ME-N-Off	9	31	9.11
4	E-N-M-ME-N-Off	0	24	10.85
5	M-M-E-EN-N-Off	15	32	3.97
6	E-M-M-EN-N-Off	9	24	7.98
Currently applied		8	56	18.66

Alternative 5, shift pattern of M-M-E-EN-N-Off, has the largest minimum between-days break-time, and it satisfies the between-days break-time constraint. The other alternatives break the between-days break-time constraint. The standard deviation of between-days break-time constraint of alternatives 5 shows the minimum value among others alternatives and also against the shift pattern currently applied. It means that the variation of between-days break-time duration in alternative 5 is the smallest. So that staff could have more evenly distribution of work and rest time. Staff has minimum 15 hours to have more quality leisure for rest, family, and social activities in each day. However, shift pattern of alternative 5 also has weakness, i.e. staff will be on duty in 2 shifts in the 5th day, to finish shift N of the 4th day until 8 a.m. in the 5th day then return to work of shift N, also in the 5th day started at 11 p.m. Nevertheless shift pattern of alternative 5 is recommended to apply because staff still has previously 15 hours of between-days break-time that satisfies the between-days break-time constraint, as well as has more evenly distribution between work and rest time. Shift pattern of M-M-E-EN-N-Off is the optimal solution for the problem, since it is the best shift pattern resulted through total enumeration approach. The proposed procedure has developed all feasible combinations of shift pattern and examined them whether they satisfy the constrain or not.

4. CONCLUSIONS

In this paper, we have developed shift pattern in cyclic scheduling for Front Office staff rostering, which its number of staff equal to number of shift type. We assign additional shift to staff as overtime in order to overcome staff shortage since a staff has one-day-off. The rule to develop the cyclic shift pattern is: (1) the cycle length is 6 days, consists of 5 days of work stretch following by 1 day for off; (2) overtime shift pattern is applied by assign 2 consecutive shifts to a staff in the same day; (3) overtime is assigned in the 4th day of 1 cycle period, i.e. 2 days before one-day-off; (4) shift type assigned in the 2nd day of 1 cycle period should has different type with overtime shift type. Recommended cyclic shift pattern is M-M-E-EN-N-Off. It has 15 hours of minimum between-days break-time that satisfy between-days break-time constraint.

Management of Disaster Oasis Training Center has accepted the resulting cyclic shift pattern, since it has better distribution of work and rest time than cyclic shift pattern that previously applied. Several considerations for future research extension are a staff on leave, weekend off requirement, and hierarchical staffs.

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AUTHOR BIOGRAPHIES

Deny Ratna Yuniarta is a lecturer in Industrial Engineering Department, Universitas Atma Jaya Yogyakarta, Indonesia. She received Master degree from the Graduate School of Industrial Engineering and Management, Institut Teknologi Bandung (ITB), Bandung in 2007. Her research interests include production scheduling, JIT systems, and production systems. Her email address is <dena@mail.uajy.ac.id>