

# **Risk Analysis and Risk Mitigation Strategies in Coal Mining Activities Using the FMECA-Fuzzy TOPSIS Method**

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## **Abstract**

Currently, the coal mining industry has a major role in national development because coal is a potential energy source that is very promising to continue to be developed. The mining industry has the characteristics of being a capital-intensive, technology-intensive, and high-risk industry. If there is a decrease in coal production, it can affect the Indonesian economic sector which is one of the largest coal producers in the world. Therefore, risk management is needed to work safety, as well as to overcome hazards in the mining area in order to support the realization of coal production targets. This paper aims to identify, analyze risks, and design risk mitigation strategies in coal mining activities using the FMECA (Failure Modes, Effect, and Criticality Analysis) - Fuzzy TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method. From this research, obtained 76 risks that have been assessed with 8 potential risk of priority accidents, as well as mitigation strategies that can be applied to overcome these risks.

## **Keywords**

Risk management, FMECA, Fuzzy TOPSIS, safety and coal mining industry.

## **1. Introduction**

Currently, the coal mining industry has a major role in national development because coal is a very good potential energy source and is very promising to continue to be developed. The mining industry is an industrial sector that is always full of challenges and has risks, both operationally and managerially in line with increasingly stringent government regulations that are constantly changing. Therefore, in order to survive and be competitive, companies must have effective and efficient risk management. Especially for mining industry, this risk management issues effective policies to address various problems that arise to mitigate hazards in the mining area.

One of the characteristics of the mining industry is that it is capital-intensive, technology-intensive, and carries great risks. One of the risks faced is an accident. In coal mines, mining activities are carried out starting from clearing the mining area, stripping overburden, extracting mineral reserves into mining products, transporting mining products to sales points, and sending mining products. In coal production activities, of course, there are many risks and hazards that can occur because mining has a high level of criticality, such as explosions, buried landslides, fires, toxic gases, extreme temperatures, the risk of using heavy equipment, and so on.

Mining risk management is an interactive process used by mining companies to identify, evaluate and mitigate hazards in the workplace in order to reduce hazard risks. Risk management requires not only management involvement but also management commitment and all related parties (Suryaningsum, et al. 2017). This study aims to analyze risks and risk mitigation strategies using the FMECA-Fuzzy TOPSIS method. With this research, risks in coal mining activities can be identified, analyzed, and mitigated, so that these risks can be minimized.

## **2. Methods**

In this study, the Failure Modes, Effects and Critically Analysis (FMECA) method, which is a development of the Failure Modes and Effects Analysis (FMEA) method, is used to identify the factors that cause risk in coal production activities and find out which factors are the most at risk with a value the highest Risk Priority Number (RPN). FMECA is a quantitative method that functions to identify potential failures by adding critical point analysis using a criticality matrix (Ibrahim et al. 2011). FMECA method was choosing in this study because FMECA is a method that combines

the FMEA method added with critical point analysis using a criticality matrix. The aim is to make an analysis of potential risks that might occur in tools, processes, and systems (Putra et al. 2017).

The results of the assessment based on the FMECA then become input for determining a mitigation strategy by integrating fuzzy logic and TOPSIS (Technique for Order Performance by Similarity to Ideal Solution). TOPSIS is a linear weighting MCDM technique originally proposed by Hwang and Yoon (1981). A fuzzy approach was adopted to remove the intrinsic difficulty of dealing with sharp values when evaluating conventional RPN values (Guimaraes, et al. 2004). Fuzzy TOPSIS is a method that can be used for decision making in determining the priority of several existing alternatives. This method is able to solve problems with the basic idea, where the selected alternative has the closest distance to the positive ideal solution and has the farthest distance to the negative ideal solution.

### 3. Data Collection

Data collection was carried out by conducting interviews and preparing research questionnaire 1. Interviews for risk identification are also re-validated by confirming with other workers. Then, questionnaires were distributed to several respondents who were company managers and staff to obtain data in order to identify and analyze existing risks. When processing data, FMECA method is carried out to carry out a risk assessment by determining the level of criticality of each risk. Next, identifying several recommended strategies for the most critical risks and distributing research questionnaire 2. To find out which strategies should be considered in risk mitigation, Fuzzy TOPSIS method is used. After processing the data, data analysis in determining the risk mitigation strategy can be carried out.

### 4. Results

Table 1 is the result of the identification and assessment of risks in coal mining activities where there are 76 risks in this activity. The RPN (risk priority number) value is obtained after the respondent determines the severity, occurrence, and detection ratings.

Table 1. Risk Assessment

Activity	Process	Code	Risk	S	O	D	RPN	
Loading coal and overburden		F41	Excavator unit collapsed	4	4	3	48	
		F42	Excavator unit upside down	6	3	4	72	
		F43	Dump truck unit collapsed	4	5	3	60	
		F44	Dump truck unit upside down	6	3	4	72	
		F45	Stuck down by loading material	6	3	3	54	
		F46	Hit by a landslide	9	3	3	81	
Emergency condition		F47	Hit by a landslide	9	3	3	81	
		F48	Trapped by landslide	9	2	3	54	
		F49	Trapped in rain flood	9	4	3	108	
		F50	Trapped in fault	7	3	3	63	
Hauling	The dump truck unit hauling coal and overburden	F51	Collision between dump truck unit and another unit	10	3	4	120	
		F52	Dump truck unit collapsed	9	3	3	81	
		F53	Dump truck unit is off track	7	5	3	105	
		F54	Dump truck unit crashed into an embankment	7	4	4	112	
		F55	Dump truck unit caught fire	7	3	3	63	
Dumping	The dump truck unit enters the dumping area	F56	Collision between dump truck unit and another unit	10	4	3	120	
		F57	Dump truck unit slipped	8	4	3	96	
		F58	Dump truck unit is stuck in soft material	5	4	3	60	
	Maneuvers in the dumping area		F59	The dump truck unit collided with another unit during a maneuver	9	4	4	144
			F60	Dump truck unit collapsed	5	4	3	60
			F61	Dump truck unit upside down	8	3	4	96
The dump truck unit do reverse activities in the dumping area		F62	Crashing into another unit while retreating	8	4	3	96	
		F63	Fall	9	4	3	108	
Do dozer activities in the dumping area		F64	Dozer unit collapsed	5	4	3	60	
		F65	Dozer unit fell	6	4	3	72	
Do dumping activities		F66	Got hit on another unit while dumping	8	4	3	96	
		F67	Unit collapses / stuck in fault	9	3	3	81	
The dump truck unit do forward activities in the dumping area		F68	Got hit on another unit	9	4	3	108	
		F69	Unit fell	7	3	3	63	
		F70	Unit collapses	6	3	3	54	
The dump truck unit leaves the dumping area		F71	Got hit on another unit	8	4	4	128	
		F72	Unit fell	6	4	3	72	
Emergency condition		F73	Hit by a landslide	9	3	4	108	
		F74	Trapped by landslide	8	3	4	96	
		F75	Trapped in rain flood	8	3	4	96	
		F76	Trapped in fault	7	2	4	56	

Activity	Process	Code	Risk	S	O	D	RPN
Land Clearing	The dozer unit goes to land clearing	F1	Vehicle unit collapsed	3	4	4	48
		F2	Narrow travel area	5	3	4	60
		F3	Stuck down by tree	8	3	4	96
		F4	Fall at different heights	8	4	5	160
		F5	Vehicle unit collapsed	5	3	4	60
		F6	Hit by a landslide	7	3	6	126
		F7	Fuel truck collapsed	3	3	5	45
		F8	Interactions between units	6	4	3	72
Refueling of the dozer unit	The dozer unit leaves the land clearing area	F9	Fall into a hole	7	3	3	63
		F10	Get hit by an MMU/emulsion truck	7	2	4	56
Charging explosives		F11	Fall into a hole	5	3	3	45
		F12	MMU / emulsion truck upside down	7	2	3	42
Securing blasting		F13	Human and equipment blockade	8	3	3	72
		F14	Human / equipment hit by explosion	10	3	3	90
Do blasting		F15	Human / equipment hit by explosion	10	2	3	60
		F16	Humans / equipment hit by throwing material	10	2	2	40
Check the blasting area		F17	Vehicle unit collapsed	6	2	3	36
		F18	Fell / slipped	7	3	3	63
Finish blasting		F19	Fell / slipped	7	2	3	42
		F20	Punched by material	8	2	3	48
Drilling	Do an initial check	F21	Hit by drilling unit	6	2	3	36
		F22	Fell / slipped	5	2	3	30
		F23	Punched by drilling door	6	2	3	36
The dozer unit prepares the drilling location		F24	Hit by dozer unit	7	2	3	42
		F25	Dozer unit upside down	8	2	3	48
		F26	Dozer unit collapsed	6	3	3	54
		F27	Fell / slipped	5	2	3	30
Installing drilling points	Do drilling	F28	Drilling unit upside down	8	2	3	48
		F29	Drilling unit slipped	7	2	3	42
		F30	Drilling unit caught fire	7	2	4	56
Move the drill unit to the next drilling point		F31	Bent drill pipe	2	2	1	4
		F32	Hit by unit	5	3	3	45
Loading	Do an initial check	F33	Fell / slipped	6	3	3	54
		F34	Punched	6	3	3	54
		F35	Excavator unit collapsed	4	4	3	48
Prepare for front loading		F36	Excavator unit upside down	7	3	3	63
		F37	Dump truck unit collapsed	5	4	3	60
		F38	Dump truck unit upside down	7	3	3	63
		F39	Collision between excavator unit and dump truck	8	3	3	72
		F40	The excavator/dump truck unit hits the small vehicle	10	4	3	120

Once there is an RPN value, prioritization can be done by sorting the failure points from largest to smallest using a Pareto chart, starting from the right of the diagram, the largest and the smallest is on the left of the diagram (Figure 1). The goal is to produce optimal improvements by focusing on priority improvements.

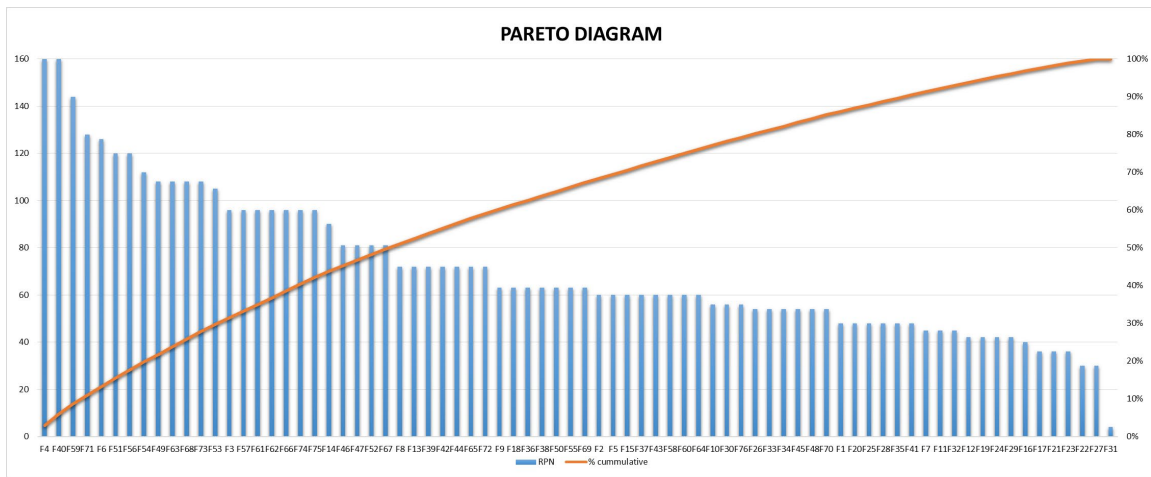


Figure 1. Pareto Chart

Accident risks that are included in the 20% biggest impact by looking at the value of the RPN will seek alternative solutions to mitigate the risk. So, from 76 risks, 20% of the priority accident risks are obtained where there are 8 potential accident risks. The criticality matrix in Figure 2 is made to determine risk priority based on the severity and level of occurrence, where if there is the same RPN value then the priority is determined based on the severity and occurrence values.

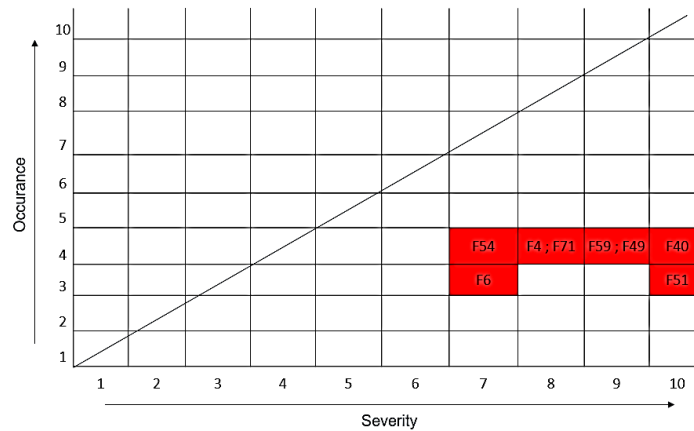


Figure 2. Criticality Matrix

Table 2. Risk Priority

Code	Risk	RPN
F40	The excavator/dump truck unit hits the small vehicle	160
F51	Collision between dump truck unit and another unit	120
F59	The dump truck unit collided with another unit during a maneuver	144
F49	Trapped in rain/flood	108
F4	Fall at different heights	160
F71	Got hit on another unit	128
F54	Dump truck unit crashed into an embankment	112
F6	Hit by a landslide	126

Based on the risk priorities that have been obtained from the FMECA method, then a risk mitigation strategy is designed using the Fuzzy TOPSIS method (Table 2). This alternative strategy was assessed by respondents who have experience in this field, where there are 28 alternative handling strategies as can be seen in Table 3, which will then be ranked using Fuzzy TOPSIS.

Table 3. Risk Management Strategy

Code	Risk Management Strategy
P1	Use Personal Protective Equipment completely
P2	Carry out activities in accordance with the Standard Operating Procedure
P3	Deliver Job Safety Analysis socialization to all related employees at the beginning of each shift
P4	Position the unit properly and do not operate the unit too far from the edge
P5	Do demarcation in the area of difference in height
P6	Do dozing activities in a safe, level and hard area
P7	Use a safety belt when operating the unit
P8	Avoid passing through areas with high differences
P9	Supervising during work
P10	Perform two-way communication between units using radio communication
P11	Maintain a safe distance min. 30 meters
P12	Ensuring vehicles entering the mine have properly installed mandatory equipment (all lights on, rotary lights, reflector tape, flags 4 meters high from the ground, and radio communication)
P13	If parking in the vicinity of heavy equipment movement, install safety cones around the vehicle and park around light towers at night
P14	Maintain a distance of +/- 10 meters with other units when maneuvering
P15	Perform the maneuver clockwise
P16	Using the horn 3x when maneuvering backwards
P17	Maintain a safety distance of 1x the length of the unit
P18	All units crossing the intersection must comply with predetermined signs
P19	Fulfillment of traffic sign equipment and carry out periodic inspections
P20	Create a waiting line for dump truck units to limit the queues of existing dump trucks
P21	Ensure that at the beginning and end of each shift supervisors must carry out inspections and observations (critical area checklist per hour) to ensure the area is safe
P22	Follow emergency procedures and escape plans
P23	If there is information from the radar due to progressive deformation movement, immediately evacuate the unit by following the evacuation route to the muster point
P24	Provide sufficient lighting during night activities
P25	Pay attention to the path to be traversed
P26	If there is information on rain / during heavy rain, immediately evacuate the unit to a safe place following the signs for the evacuation route to the muster point
P27	Park the unit in a safe area when it rains, not in an area that has the potential to flood
P28	If an emergency occurs, the operator or supervisor must contact the Emergency Response Team

Fuzzy TOPSIS is a method that can be used for decision making in determining the priority of several existing alternatives. This method is able to solve problems with the basic idea, where the selected alternative has the closest distance to the positive ideal solution and has the farthest distance to the negative ideal solution (Table 4).

Table 4. Fuzzy TOPSIS Calculation Results

	$d^+$	$d^-$	$v_i$	Rank
P1	0,447	0,669	0,599	3
P2	0,430	0,711	0,623	1
P3	0,447	0,669	0,599	4
P4	0,644	0,359	0,358	19
P5	0,691	0,303	0,305	22
P6	0,740	0,293	0,284	24
P7	0,508	0,467	0,479	8
P8	0,658	0,381	0,366	18
P9	0,530	0,536	0,503	7
P10	0,618	0,513	0,453	10
P11	0,650	0,489	0,429	12
P12	0,650	0,489	0,429	13
P13	0,673	0,488	0,420	14
P14	0,751	0,255	0,254	27
P15	0,778	0,244	0,239	28
P16	0,764	0,278	0,267	26
P17	0,659	0,392	0,373	17
P18	0,586	0,523	0,472	9
P19	0,530	0,601	0,531	6
P20	0,672	0,373	0,357	20
P21	0,588	0,444	0,430	11
P22	0,620	0,410	0,398	15
P23	0,743	0,351	0,321	21
P24	0,430	0,711	0,623	2
P25	0,486	0,613	0,558	5
P26	0,761	0,282	0,270	25
P27	0,750	0,309	0,292	23
P28	0,615	0,374	0,378	16

From the alternative strategies that have been recommended, the most influential strategy is obtained to overcome the existing priority risks based on the ranking of alternative strategies. P2 (carry out activities in accordance with the Standard Operating Procedure) has the highest score so it is in the first rank, P24 (provide sufficient lighting during night activities) is in the second rank, and P1 (use Personal Protective Equipment completely) is in the third rank. However, other alternative solutions are also considered and not ruled out to minimize the risk of potential accidents in coal mining.

## 5. Conclusion

Based on the research results, it can be concluded that 76 potential accident risks in coal mines are identified. Of the 76 accident risks, there are 8 potential accident risks included in the 20% Pareto chart. Based on the FMECA method, the highest priority risk is F40 (the excavator/dump truck unit hits the small vehicle), F51 (collision between dump truck unit and another unit), F59 (the dump truck unit collided with another unit during a maneuver), F49 (trapped in rain/flood), F4 (fall at different heights), F71 (got hit on another unit), F54 (dump truck unit crashed into an embankment, and F6 (hit by a landslide). Of the 8 risks, 28 risk mitigation strategies were recommended which were then ranked using the Fuzzy TOPSIS method. The top 3 rankings of mitigation strategies are occupied by P2 (carry out activities in accordance with the Standard Operating Procedure), P24 (provide sufficient lighting during night activities), and P1 (use Personal Protective Equipment completely).

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**Appendix**

**Table 5. Defuzzification Matrix**

	A1	A2	A3	A4	A5	A6	A7	A8
<b>P1</b>	1	1	1	1	1	1	0,8	1
<b>P2</b>	1	1	1	1	1	1	1	1
<b>P3</b>	1	1	1	1	1	1	0,8	1
<b>P4</b>	1	0,6	0,6	0,4	0,8	0,4	0,8	0,4
<b>P5</b>	1	0,2	0,4	0,4	0,6	0,4	0,6	0,8
<b>P6</b>	1	0,2	0,4	0,2	0,8	0,2	0,4	0,4
<b>P7</b>	1	0,8	0,8	0,8	0,8	0,8	0,8	0,8
<b>P8</b>	1	0,4	0,4	0,4	0,8	0,4	0,6	1
<b>P9</b>	1	0,6	1	0,8	1	0,8	0,6	1
<b>P10</b>	0,8	1	1	1	0,4	1	0,4	0,6
<b>P11</b>	0,4	1	1	1	0,4	1	0,4	0,4
<b>P12</b>	0,4	1	1	1	0,4	1	0,4	0,4
<b>P13</b>	0,4	1	1	1	0,2	1	0,2	0,4
<b>P14</b>	0,2	0,4	1	0,6	0,2	0,6	0,2	0,4
<b>P15</b>	0,2	0,6	1	0,2	0,2	0,2	0,2	0,4
<b>P16</b>	0,4	0,8	1	0,2	0,2	0,2	0,2	0,4
<b>P17</b>	0,2	0,6	0,8	1	0,4	1	0,6	0,4
<b>P18</b>	0,4	1	1	1	0,4	1	0,8	0,6
<b>P19</b>	0,6	1	1	1	0,8	1	1	0,6
<b>P20</b>	0,2	0,6	0,6	1	0,4	1	0,6	0,4
<b>P21</b>	1	0,6	0,6	0,8	1	0,8	0,4	0,8
<b>P22</b>	0,8	0,6	0,6	0,6	1	0,6	0,6	1
<b>P23</b>	0,6	0,2	0,2	0,2	1	0,2	0,4	1
<b>P24</b>	1	1	1	1	1	1	1	1
<b>P25</b>	1	1	0,8	1	0,6	1	1	0,8
<b>P26</b>	0,6	0,2	0,2	0,2	0,8	0,2	0,2	1
<b>P27</b>	0,8	0,2	0,2	0,2	0,8	0,2	0,2	1
<b>P28</b>	0,8	0,6	0,8	0,6	0,8	0,6	0,6	1

**Table 6. Normalized Matrix**

	A1	A2	A3	A4	A5	A6	A7	A8
<b>P1</b>	0,245	0,253	0,232	0,245	0,259	0,245	0,242	0,248
<b>P2</b>	0,245	0,253	0,232	0,245	0,259	0,245	0,303	0,248
<b>P3</b>	0,245	0,253	0,232	0,245	0,259	0,245	0,242	0,248
<b>P4</b>	0,245	0,152	0,139	0,098	0,207	0,098	0,242	0,099
<b>P5</b>	0,245	0,051	0,093	0,098	0,155	0,098	0,182	0,199
<b>P6</b>	0,245	0,051	0,093	0,049	0,207	0,049	0,121	0,099
<b>P7</b>	0,245	0,202	0,185	0,196	0,207	0,196	0,242	0,199
<b>P8</b>	0,245	0,101	0,093	0,098	0,207	0,098	0,182	0,248
<b>P9</b>	0,245	0,152	0,232	0,196	0,259	0,196	0,182	0,248
<b>P10</b>	0,196	0,253	0,232	0,245	0,103	0,245	0,121	0,149
<b>P11</b>	0,098	0,253	0,232	0,245	0,103	0,245	0,121	0,099
<b>P12</b>	0,098	0,253	0,232	0,245	0,103	0,245	0,121	0,099
<b>P13</b>	0,098	0,253	0,232	0,245	0,052	0,245	0,061	0,099
<b>P14</b>	0,049	0,101	0,232	0,147	0,052	0,147	0,061	0,099
<b>P15</b>	0,049	0,152	0,232	0,049	0,052	0,049	0,061	0,099
<b>P16</b>	0,098	0,202	0,232	0,049	0,052	0,049	0,061	0,099
<b>P17</b>	0,049	0,152	0,185	0,245	0,103	0,245	0,182	0,099
<b>P18</b>	0,098	0,253	0,232	0,245	0,103	0,245	0,242	0,149
<b>P19</b>	0,147	0,253	0,232	0,245	0,207	0,245	0,303	0,149
<b>P20</b>	0,049	0,152	0,139	0,245	0,103	0,245	0,182	0,099
<b>P21</b>	0,245	0,152	0,139	0,196	0,259	0,196	0,121	0,199
<b>P22</b>	0,196	0,152	0,139	0,147	0,259	0,147	0,182	0,248
<b>P23</b>	0,147	0,051	0,046	0,049	0,259	0,049	0,121	0,248
<b>P24</b>	0,245	0,253	0,232	0,245	0,259	0,245	0,303	0,248
<b>P25</b>	0,245	0,253	0,185	0,245	0,155	0,245	0,303	0,199
<b>P26</b>	0,147	0,051	0,046	0,049	0,207	0,049	0,061	0,248
<b>P27</b>	0,196	0,051	0,046	0,049	0,207	0,049	0,061	0,248
<b>P28</b>	0,196	0,152	0,185	0,147	0,207	0,147	0,182	0,248

Table 7. Weighted Normalized Matrix

	A1	A2	A3	A4	A5	A6	A7	A8
P1	0,245	0,253	0,232	0,245	0,259	0,245	0,182	0,248
P2	0,245	0,253	0,232	0,245	0,259	0,245	0,303	0,248
P3	0,245	0,253	0,232	0,245	0,259	0,245	0,182	0,248
P4	0,245	0,076	0,070	0,024	0,155	0,024	0,182	0,025
P5	0,245	0,000	0,023	0,024	0,078	0,024	0,091	0,149
P6	0,245	0,000	0,023	0,000	0,155	0,000	0,030	0,025
P7	0,245	0,152	0,139	0,147	0,155	0,147	0,182	0,149
P8	0,245	0,025	0,023	0,024	0,155	0,024	0,091	0,248
P9	0,245	0,076	0,232	0,147	0,259	0,147	0,091	0,248
P10	0,147	0,253	0,232	0,245	0,026	0,245	0,030	0,074
P11	0,025	0,253	0,232	0,245	0,026	0,245	0,030	0,025
P12	0,025	0,253	0,232	0,245	0,026	0,245	0,030	0,025
P13	0,025	0,253	0,232	0,245	0,000	0,245	0,000	0,025
P14	0,000	0,025	0,232	0,073	0,000	0,073	0,000	0,025
P15	0,000	0,076	0,232	0,000	0,000	0,000	0,000	0,025
P16	0,025	0,152	0,232	0,000	0,000	0,000	0,000	0,025
P17	0,000	0,076	0,139	0,245	0,026	0,245	0,091	0,025
P18	0,025	0,253	0,232	0,245	0,026	0,245	0,182	0,074
P19	0,074	0,253	0,232	0,245	0,155	0,245	0,303	0,074
P20	0,000	0,076	0,070	0,245	0,026	0,245	0,091	0,025
P21	0,245	0,076	0,070	0,147	0,259	0,147	0,030	0,149
P22	0,147	0,076	0,070	0,073	0,259	0,073	0,091	0,248
P23	0,074	0,000	0,000	0,000	0,259	0,000	0,030	0,248
P24	0,245	0,253	0,232	0,245	0,259	0,245	0,303	0,248
P25	0,245	0,253	0,139	0,245	0,078	0,245	0,303	0,149
P26	0,074	0,000	0,000	0,000	0,155	0,000	0,000	0,248
P27	0,147	0,000	0,000	0,000	0,155	0,000	0,000	0,248
P28	0,147	0,076	0,139	0,073	0,155	0,073	0,091	0,248