# Contaminant Source Identification in River Networks

# A Probabilistic Analysis and Application to Altamaha River

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• We can easily determine a region for the spill if we know the first activated

• Can we find a set of junctions in that region as possible spill locations?

## Spill Example





### Parameterization of Concentration Profile

Parameter 1: M<sub>max</sub>/M<sub>tot</sub>



# Parameterization of Concentration Profile

Parameter 2: Peclet Number

$$Pe = \frac{\left(\sum_{k:C_k > threshold} \frac{1}{v_k} v_k \Delta t\right)^2}{\sum_{k:C_k > threshold} \frac{D_k}{v_k^3} v_k \Delta t}$$

$$D = 0.011 \frac{v^2 B^2}{dU_*} \text{ (Fisher et al. 1979)}$$
$$\left(\sum_{k:C_k > threshold} \Delta t\right)^2$$

$$Pe = \frac{1}{\sum_{k:C_k > threshold} 0.011 \left(\frac{B^2}{dU_*}\right)_k \Delta t}$$

- v: velocity
- D: Dispersion coefficient
- *B* : Top width
- d: depth of flow
- $U_*$ : Shear velocity



$$\frac{B^2}{dU_*} = \frac{B^2}{d\sqrt{gRS_o}}$$

$$\frac{B^2}{dU_*} = \frac{B^2}{d\sqrt{g\left(\frac{Bd-d^2z}{2\sqrt{d^2z^2+d^2}} + B - 2dz\right)}S_o}$$

$$\frac{B^2}{dU_*} \propto \frac{L^2}{L^{3/2}} \text{ assuming } g \text{ and } S_o \text{ as constants.}$$

Therefore for small changes in depth,

 $Pe \propto \sum_{k:C_k > threshold} \Delta t = Detection period$ 



#### Comparison of the two parameters



Pe gives information about support base (or detection period)

Mmax/Mtot gives information about vertical scale of the profile

#### **Scenario Generation**



# Characterization of Scenario Results in terms of Parameter 1 and 2



#### **Random Variables**

In our analysis a spill must have three main properties:

 $X_1: M_{\text{max}}/M_{\text{tot}}$  observed at the monitoring station.

 $X_2$ : Pe observed at the monitoring station.

*Y*: Junction where the spill has occured.

Features of the spill event

Class of the spill event



# Conditional prior probability densities



f(X/Y): Conditional probability density function of  $X \in \{X_1, X_2\}$  given that spill occured at Y approximated from Kernel density estimation.



P(Y|X): Conditional probability of  $Y \in \Omega$  given that spill has feature of  $X \in \{X_1, X_2\}$ 



# Conditional prior joint probability densities

Copula Concept:

 $f(X_1, X_2 | Y) = c(F(X_1 | Y), F(X_2 | Y))f(X_1 | Y)f(X_2 | Y)$ 

Frank Copula:

$$c(F_X(x), F_Y(y)) = -\frac{\theta \exp(-\theta(F_X(x) + F_Y(y)))(\exp(-\theta) - 1)}{\left[\exp(-\theta(F_X(x) + F_Y(y)) - \exp(-\theta F_X(x) - \exp(-\theta F_Y(y)) + \exp(-\theta)\right]^2}$$

- c(u,v) : Copula density function,  $\theta$ :copula parameter
- F(X/Y) : Conditional marginal cumulative distribution of  $X \in \{X_1, X_2\}$  given that spill has occured at Y.
- $f(X_1, X_2/Y)$ : Conditional joint probability density of  $X_1$  and  $X_2$  given that spill has occured at Y.







# Summary of statistical analysis

Up to now, we can estimate three conditional probability values:

 $P(Y|X_1)$ : Conditional probability of  $Y \in \Omega$ given that spill has feature of  $X_1$ 

 $P(Y|X_2)$ : Conditional probability of  $Y \in \Omega$ given that spill has feature of  $X_2$ 

 $P(Y|X_1, X_2)$ : Conditional joint probability of  $Y \in \Omega$ given that spill has features of  $X_1$  and  $X_2$ .

How can we use this information to determine most possible classes, *Y* (or junctions) for a spill event having features  $x_1$  and  $x_2$ ?





 Adaptive Feature Selection in Pattern Recognition and Ultra-Wideband Radar Signal Analysis; Phd Thesis by Hao Jiang ,CalTech, 2008.
 Problem Statement:

Let (X,Y) be a pair of random variables:  $X \in \mathbb{R}^d$ ,  $Y \in \{1,2,...M\}$  where *M* is the number of classes or patterns.

 $D_n = \{ (X^1, Y^1), (X^2, Y^2), \dots, (X^n, Y^n) \}$  is the tarining set with elements being i.i.d. samples from a fixed but unknown distribution governing (X, Y).

$$\boldsymbol{X} = \begin{bmatrix} \boldsymbol{X}_1 & \boldsymbol{X}_2 & \dots & \boldsymbol{X}_d \end{bmatrix}^T$$

Assume that the classes *Y* take a prior distribution  $\{P(Y = j), j = 1, 2, ..., M\}$ 

The goal is to find a mapping g:  $\mathbb{R}^d \to \{1, 2, ..., M\}$  such that an arbitrary unlabeled test data  $x = \begin{bmatrix} x_1 & x_2 & ... & x_d \end{bmatrix}^T \in \mathbb{R}^d$  can be classified into one of the M classes while optimizing some criterion.



Optimum Feature Selection:

Entropy corresponding to prior p.m.f:

$$H_0 = -\sum_{i=1}^{M} P(Y=i) \log \left[ P(Y=i) \right], \text{ to be unbiased } P(Y=j) = \frac{1}{M}, \ j = 1, \dots, M$$

Class entropy conditioned on the sample *x<sub>i</sub>*:

$$H_{i} = -\sum_{j=1}^{M} P(Y = j / X_{i} = x_{i}) log \left[ P(Y = j / X_{i} = x_{i}) \right]$$

The quantity  $H_0$ - $H_i$  measures how well the feature  $x_i$  (which is the i<sup>th</sup> component of the unlabeled test data x) reduces the complexity of the classification task.

$$q(x_i) = H_0 - H_i$$

The best feature in terms of reducing the class entropy can be selected as:

$$x_* = \underset{x_i \in \{x_1, \dots, x_d\}}{\operatorname{argmax}} q(x_i)$$







- Original form of ASFS algorithm reduces the initial class set to one final selected class by eliminating the classes using a probability threshold.
- However, final result is not always the correct answer.
- We have made some modifications to add some flexibility to ASFS algorithm.
  - We introduced a copula set  $\Omega_c$  in which we store some eliminated classes according to their performance against a joint probability threshold.
  - We determined a criterion to stop ASFS algorithm at some level where the correct class is in the final set.
  - At the end of one ASFS cycle (according to our new stopping criteria), we added copula set into final class set obtained and re-ran ASFS algorithm.
  - This modified ASFS algorithm is stopped when two consecutive copula sets obtained are the same.







Spill_number:	1																		
Spill_between:	2	3																	
FS	Ρ	Ρ	Ρ	Ρ	Ρ	Р	Ρ	Р	Ρ	Р	Р	Ρ	Ρ	Ρ	Ρ	Р	Ρ		1
Hr	1	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.96	0.93	0.89	0.85	
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	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	6	
	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	6	15	1
	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	15	16	1
	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	15	16	24	1
	7	7	7	7	7	7	7	7	7	7	7	7	15	15	15	16	24		1
	8	8	8	8	8	10	11	11	11	13	13	15	16	16	16	24			1
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	16	16	16	17	17	18	21	24											 1
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Spill_between:	2	3																	
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Hr	1	0.97	0.93	0.9	0.86														
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	2	2	2	2	2														
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	2	0.25	0.2	0.19	0.21	-		-											
	4	0.01	0.03	0.03	0.02	•													
	6	0.22	0.22	0.18	0.21														
	15	0.01	0.05	0.03	0.03														
	16	0.15	0.17	0.17	0.17														 1
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Result_for_spill	5 6 7 16 21 24 12 4 12 wh J 1 2 2 wh	5_anc C 0.04	16 21 24 	21 24 Pe 0.13 0.25	Avg 0.06 0.18															
Result_for_spill	5 6 7 16 21 24 J J 1 2 3	5_anc C 0.04 0.09	16 21 24 MM 0.01 0.07 0.19	21 24 Pe 0.13 0.25 0.1	Avg 0.06 0.18 0.13															
 Result_for_spill	5 6 7 16 21 24 2 4 2 4 2 4 2 4 2 4	5_anc C 0.04 0.12	16 21 24 MM 0.01 0.07 0.19 0.03	21 24 Pe 0.13 0.25 0.1 0.2	Avg 0.06 0.18 0.13 0.11															
Result_for_spill	5 6 7 16 21 24 J 1 2 4 J 3 6 7	5_anc C 0.04 0.12 0.09 0.12 0	16 21 24 0.01 0.01 0.07 0.19 0.03 0.43	21 24 Pe 0.13 0.25 0.1 0.2 0.01	Avg 0.06 0.18 0.13 0.11 0.15															
Result_for_spill	5 6 7 16 21 24 1 2 4 1 2 4 3 6 7 7 21	5_anc C 0.04 0.12 0.09 0.12 0 0	16 21 24 0.01 0.07 0.19 0.03 0.43 0.18	21 24 Pe 0.13 0.25 0.1 0.2 0.01 0.2	Avg 0.06 0.18 0.13 0.11 0.15 0.06															

Results



Results



Spill_number:	3																				
Spill_between:	7	8																			
FS	Ρ	P	Р	Р	Ρ	P	P	Р	P	P	Ρ	Ρ	Ρ	Ρ	P	Ρ	Ρ	M	M	M	
Hr	1	1	1	1		1	1	1	1	1	1 1	1	1	1	1	1	0.99	0.94	0.94	0.93	0.
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	6	6	6	6	i 6	6 6	6 6	6 1	6	6	7 8	8 8	8 8	8	8	9	21	21	25		
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Spill_number:	5																				
Spill_between:	4	8	<b>_</b>																		
FS	M	Р	P					_	_	_							-				
Hr	1	0.91	0.81						_		_										
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Result_for_spil	7 8 9 21 25 	8 9 21 25 7_and	8925																		
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 Result_for_spil	7 8 9 21 25 1 3 4 J 8 9	8 9 21 25 7_and C 0.13 0.42	8 9 25 8 MM 0.17 0.38	Pe 0.21 0.41	Avg 0.17																
 Result_for_spil	7 8 9 21 25 3 4 3 8 9 21	8 9 21 25 7_and C 0.13 0.42 0.01	8 9 25 8 MM 0.17 0.38 0.06	Pe 0.21 0.41 0.03	Avg 0.17 0.4'	7 <b>4</b>															



Spill_number:	4														
Spill_between:	10	11													
FS	P	Ρ	Ρ	Ρ	Р	Ρ	Ρ	Ρ	Ρ	Ρ	Ρ	Ρ	Ρ	Р	
Hr	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.91	0.78
	1	1	1	1	1	1	1	1	4	4	4	10	10	11	11
	2	2	2	2	2	2	4	4	5	5	10	11	11	12	13
	3	3	3	4	4	4	5	5	10	10	11	12	12	13	14
	4	4	4	5	5	5	6	10	11	11	12	13	13	14	17
	5	5	5	6	6	6	10	11	12	12	13	14	14	17	
	6	6	6	10	10	10	11	12	13	13	14	17	17		
	7	7	10	11	11	11	12	13	14	14	17	18			
	8	10	11	12	12	12	13	14	15	17	18				
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Spill_number:	4														
Spill_between:	10	11	-												
FS	P	M	Р 												
Hr	1	0.86	0.7												
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	12	13	13												
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Denville from 11		40	4.4												
Result_for_spill	14_W	110_an	11	<b>D</b> -	0										
	J	U 0.24	INIM 0.25	Pe 0.00	AVg										
	11	0.31	0.35	0.23	0.3	-									
	13	0.32	0.34	0.25	0.3										
	14	0.27	0.18	0.37	0.27										
	17	U.1	0.13	0.15	0.13										



Spill_number:	5													
Spill_between:	14	9												
FS	Ρ	Р	Р	Р	Р	Р	Р	Р	Р	Р	M	Р	M	
Hr	1	1	1	1	1	1	1	1	1	1	0.97	0.93	0.87	0.83
	1	1	1	1	1	1	1	1	4	4	4	4	11	11
	2	2	2	2	2	2	4	4	5	5	10	11	12	13
	3	3	3	4	4	4	5	5	5 10	10	11	12	13	14
	4	4	4	5	5	5	6	10	11	11	12	13	14	17
	5	5	5	6	6	6	10	11	12	12	13	14	17	18
	6	6	6	10	10	10	11	12	2 13	13	14	17	18	
	7	7	10	11	11	11	12	13	3 14	14	17	18		
	8	10	11	12	12	12	13	14	15	17	18			
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	10	12	13	13										
	12	14	14	14										
	13	14	10	17										
	14	17	10											
	17	18												
	10													
Result_for_spill	5_wł	14_an	9											
	J	С	MM	Pe	Avg									
	11	0.1	0.09	0.17	0.12									
	13	0.11	0.1	0.16	0.12									
	14	0.43	0.28	0.29	0.33	-								
	17	0.29	0.19	0.32	0.27									
	18	0.08	0.34	0.06	0.16									

Res	ults		Spill_number: Spill_between: FS Hr	N
	20	21	Spill_number: Spill_between: FS Hr	
~	25	ð		

	Spill_number:	6																
	Spill between:	9	19															
	FS	M	М	М	М	М	М	М	М	М	М	М	М	Р	Р	Р	Р	
	Hr	1	1	1	1	1	1	1	1	1	1	1	1	0.84	0.84	0.83	0.81	0.73
,		1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	7	
		2	2	2	2	2	2	2	2	2	2	2	3	3	- 3	7	8	8
			3	3	3	3	3	3	3	3	3	3	7	7	7	. 8	9	(
		4	4	4	4	4	5	5	7	7	7	7			8	q	21	2
		5	5	5	5	5	с а	7	8	8	8	8	a	a	a	21	21	2.
		6	6	6	6	6	7	· ·	0	0	0	0	21	21	21	21	20	
		7	7	7	7	7		0	17	10	10	3	21	21	21	20		
							0	17	1/	10	19	21	22	24	25			
			0	0	0	0	9	17	10	19	21	22	24					
		9	9	9	9	9	17	18	19	21	22	24	25					
		10	15	15	16	17	18	19	21	22	24	25						
		11	16	16	17	18	19	21	22	24	25							
		12	17	17	18	19	21	22	24	25								
		13	18	18	19	21	22	24	25									
		14	19	19	21	22	24	25										
		15	21	21	22	24	25											
		16	22	22	24	25												
		17	24	24	25													
		18	25	25														
		19	26															
		20	1															
		21																
		22	1															
		23																
		20																
		24																
		20																
		20																
•																		
3																		
- 21		_																
t	Spill_number:	6																
	Spill_between:	9	19															
5	FS	P	M	М	M													
	Hr	1	0.9	0.9	0.7													
22		7	7	8	9													
<b>20</b>		8	8	9	25													
		9	9	25														
		21	25															
$\lambda_{\alpha}$		25																
4226																		
~~~																		
				40														
5	December 2	ue				1	1			1	1	1		1			1	
5	Result_for_spil	1 <u>6_</u> w	r9_and	19 MM	Do	Ava												
- <b>h</b>	Result_for_spil	l <u>6</u> w J	r9_and C	MM	Pe	Avg												
<b>-h</b>	Result_for_spil	I_6_w J 8	r9_and C 0.02	MM 0.06	Pe 0.07	Avg 0.05												



Spill_between:	18	19																	
FS	Ρ	Ρ	Ρ	Ρ	Ρ	Ρ	Ρ	Ρ		Р	M	М	М	М	М	M	М	Ρ	
Hr	1	1	1	1	1	1		1	1	1	0.94	0.94	0.94	0.94	0.93	0.91	0.89	0.86	0.83
	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	3		3	3	3	3	3	3	3	3	3	3	3	6
	4	4	4	4	4	4	-	4	4	4	4	4	4	4	4	4	4	6	16
	5	5	5	5	5	5	:	5	5	5	5	5	5	5	5	6	6	16	18
	5	5	5	5	5	5	-	7	5	5	b 44	b 44	b 14	b 17	b 17	15	10	18	24
						10	1	1	11	11	10	14	14	15	15	10	18	24	
	0	0	0	10	10	10	11	1	10	10	1/	14	10	10	10	10	24		
	10	10	9	11	10	10	11	2	12	1.1	14	19	10	17	24	24			
	11	11	11	12	12	12	1.	1	14	14	10	17	1/	24	24				
	12	12	12	12	12	14	1/	4 5	15	16	17	18	24	24					
	13	12	13	14	14	15	10	5	16	17	18	24	24						
	14	14	14	15	15	16	1	7	17	18	24	24							
	15	15	15	16	16	17	18	R	18	24	24								
	16	16	16	17	17	18	2	1	24	24									
	17	17	17	18	18	21	2	4											
	18	18	18	21	21	24													
	19	21	21	24	24				_										
	20	22	24	25															
	21	24	25																
	22	25						-											
	23																		
	24																		
	25																		
	26																		
Spill number:	7																		
Spill between:	18	19																	
FS	M	Ρ	М	Ρ															
Hr	1	0.97	0.93	0.86															
	1	1	1	1															
	2	2	2	2															
	3	3	6	6															
	5	6	16	16															
	6	16	18	24															
	16	18	24																
	18	24																	
	24																		
								_											
Result_for_spill	7_wł	18_an	19		•			_											
	J	C	MM	Pe	Avg			_											
	1	0.1	0.1	0.14	0.11			_											
	2	0.18	0.34	0.16	0.23			_											
	6	0.16	0.16	0.2	0.17			_											
	16	0.21	0.15	0.22	0.19														
	18	0.04	0.06	0.03	0.04			_											
	24	0.31	0.19	0.26	0.25														

Resu	Jlts	5 4 2
ber:         8	P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P       P	

R	es	u	lts
	<u> </u>		



Snill hetween	24	25													-		-				
opin_between.	- <u>24</u>		<b>D</b>	D	n	n .	n	n	n	n	D	D	D	D	n	D	n	D	<b>D</b>	6.4	
го 	F	F 4	F 4	F 4	F 4	F 4	F 4	F 4	F	F	F	F	F	F	F 4	F	F	F 1	F	IVI O O	
Hr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.9	U.
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	7	
	2	2	2	2	2	2	2	2	2	2 2	2 2	2	2 2	2 2	3	3	3	3	7	8	
	3	3	3	3	3	3	3	3	3	3 3	3 3	1 3	3 3	3 3	6	6	7	7	8	9	
	4	4	4	4	4	4	4	4	1	1 7	1 6	E P	S 6	S 6	7	7	8	8	q	21	
											2 7		7 7	, 7	6			0	21	21	
	0		0	0	0	0		0						· · · ·	0	0	3	3	21	25	
	6	6	6	6	6	6	6	6	6	) /	8	1 2	5 6	8 8	9	9	21	21	- 25		
	7	7	7	7	7	7	7	7	7	' 8	3 9	9	9 9	9 9	21	21	24	25			
	8	8	8	8	8	8	8	8	6	3  9	9  16	17	7 17	21	22	24	25				
	9	9	9	9	9	9	9	9	9	9 18	6 17	18	3 21	22	24	25					
	10	10	11	11	11	11	13	15	18	6 17	/ 18	21	22	24	25						
	11	11	12	13	13	13	15	16	17	/ 18	3 21	22	24	1 25							
	12	12	13	14	14	15	16	17	18	2 21	27	2/	1 26	:							
	12	12	1.4	14	14	10	10	10	24	2	22	24	+ 20	,							
	13	13	14	10	10	10	- 17	10	2	24	24	20	)								
	14	14	15	16	16	17	18	21	24	2 22	25	-									
	15	15	16	17	17	18	21	22	24	1 25	5										
	16	16	17	18	18	21	22	24	25	5											
	17	17	18	19	21	22	24	25													
	18	18	19	21	22	24	25														
	19	19	21	22	24	25															
	20	21	21	24	27	25															
	20	21	22	24	29																
	21	22	24	- 25																	
	22	24	- 25																		
	23	25																			
	24																				
	25																				
	26																				
												-									
Spill_number:	9																				
Spill between:	24	25																			
ES	Р	P	М	Р																	
Hr	. 1	n aa	 n a																		
1.11		0.00	0.9	0.00									-								
	2	- -		/						-	-		-	-	-	-	-	-			
	3	- 1	8	8																	
	7	8	9	9																	
	8	9	21	21																	
	9	21	25																		
	21	25																			
	25													-							
	2.5																				
						1								-	-		-	-			
	-									_	_		_								
Result_for_spill	9_wł	24_an	25																		
	J	С	MM	Pe	Avg																
	7	0.54	0.45	0.03	0.34																
	8	0.36	0.35	0.1	0.27																
	a	<u>п</u>	0	0.45	0.15																
	24	0.14	0.2	0.40	0.13																
	21	0.11	0.2	0.02	0.11													-			
	25	U	U U	U.4	0.13	•				1	1	1	1								





Chill had the																
Spill betwee	27	28														
FS	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Ρ	
Hr	. 1	. 1	1	1	. 1	1	. 1	. 1	1	0.99	0.98	0.97	0.95	0.94	0.89	0.85
	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	35
	29	29	29	29	32	32	32	34	34	34	34	34	35	35	35	39
	30	30	32	32	34	34	34	35	35	35	35	35	37	38	39	40
	31	32	34	34	35	36	35	36	37	37	37	37	38	30	40	40
	20	24	25	25	20	20	20	27	20	20	20	20	20	40	40	40
	32	25	20	20	27	27	27	20	20	20	20	20	40	40	40	40
	- 33	30	30	30	37	37		30	39	39	39	39	40	40	40	
	- 34	30	37	37	30	30	30	- 39	40	40	40	40	43	45		
	35	37	38	38			- 39	40	41	41	41	43	45			
	36	38	- 39	- 39	40	40	40	41	42	42	43	45				
	37	39	40	40	41	41	41	42	43	43	45					
	- 38	40	41	41	42	42	42	43	45	45						
	- 39	41	42	42	43	43	43	45	- 74							
	40	42	43	43	44	44	- 45	- 74								
	41	43	44	44	45	45	- 74									
	42	44	45	45	46	74										
	43	45	46	46	74											
	44	46	74	74												
	45	74	75													
	46	75														
	74															
	75															
	75															
	70															
	70															
	70															
	79															
	80															
	1															
Spill_number	1	28														
Spill_number Spill_betwee	1 27 P	28	P	P	P											
Spill_number Spill_betwee FS	1 27 P	28 P	P	P	P											
Spill_number Spill_betwee FS Hr	1 27 P 1 37	28 P 0.99	P 0.97	P 0.92	P 0.85											
Spill_number Spill_betwee FS Hr	1 27 P 1 27	28 P 0.99 27	P 0.97 27	P 0.92 27	P 0.85 27											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28	28 P 0.99 27 28	P 0.97 27 28	P 0.92 27 35	P 0.85 27 39											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35	28 P 0.99 27 28 35	P 0.97 27 28 35	P 0.92 27 35 39	P 0.85 27 39 40											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 35	28 P 0.99 27 28 35 39	P 0.97 27 28 35 39	P 0.92 27 35 39 40	P 0.85 27 39 40 43											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40	28 P 0.99 27 28 35 39 40	P 0.97 27 28 35 39 40	P 0.92 27 35 39 40 43	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41	28 P 0.99 27 28 35 39 40 41	P 0.97 27 28 35 39 40 43	P 0.92 27 35 39 40 43 45	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr	1 27 P 27 28 35 39 40 41 42	28 P 0.99 27 28 35 39 40 41 43	P 0.97 27 28 35 39 40 43 43 45	P 0.92 27 35 39 40 43 43 45	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr	1 27 27 28 35 39 40 41 42 43	28 P 0.99 27 28 35 39 40 41 41 43 45	P 0.97 27 28 35 39 40 43 45	P 0.92 27 35 39 40 43 45	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 41 42 43 45	28 P 0.99 27 28 35 39 40 41 43 45	P 0.97 27 28 35 39 40 43 45	P 0.92 27 35 39 40 43 45	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 45	28 P 0.99 27 28 35 39 40 41 43 45	P 0.97 27 28 35 39 40 43 45	P 0.92 27 35 39 40 43 45	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 45	28 P 0.99 27 28 35 39 40 41 43 45	P 0.97 27 28 35 39 40 43 45	P 0.92 27 35 39 40 43 45	P 0.85 27 39 40 43 45											
Spill_number Spill_betwee FS Hr Result	1 27 P 1 27 28 35 39 40 41 42 43 45 for	28 P 0.99 27 28 35 39 40 41 43 45 spill	P 0.97 27 28 35 39 40 43 45	P 0.92 27 35 39 40 43 45	P 0.85 27 39 40 43 45	is	betwee	27	and	28						
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 45 for J	28 P 0.99 27 28 35 39 40 41 43 45 spill C	P 0.97 27 28 35 39 40 43 45 	P 0.92 27 35 39 40 43 45 	P 0.85 27 39 40 43 45 45 which Avg	is	betwee	27	and	28						
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 45 for J 27 7 7	28 P 0.99 27 28 35 39 40 41 43 45 spill C 0.065	P 0.97 27 35 39 40 43 45 	P 0.92 27 35 39 40 43 45 	P 0.85 27 39 40 43 45 	is	betwee	27	and	28						
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 45 for J 27 35	28 P 0.99 27 28 35 39 40 41 43 45 5 9 20 5 9 20 5 9 20 5 9 20 5 20 5 20	P 0.97 27 28 35 39 40 43 45 45 MM 0.09 0.05 0.09	P 0.92 27 35 39 40 43 45 40 43 45 9 0.077 0.046	P 0.85 27 39 40 43 45 	is	betwee	27	and	28						
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 45 for J 27 35 39	28 P 0.99 27 28 35 39 40 41 43 45 0.01 5 5 0.028 0.028 0.231	P 0.97 28 35 39 40 43 45 	P 0.92 27 35 39 40 43 45 	P 0.85 27 39 40 43 45 	is	betwee	27	and	28						
Spill_number Spill_betwee FS Hr	1 27 P 1 27 28 35 39 40 41 42 43 43 5 7 7 7 35 39 40 27 35 39 40	28 P 0.99 28 35 39 40 41 43 45 0.05 0.065 0.028 0.231 0.095	P 0.97 27 28 35 39 40 43 45 9 40 43 45 0 9 0 0 40 0 43 45 0.09 0.05 0.028 0.05 0.28	P 0.92 27 35 39 40 43 45 	P 0.85 27 39 40 43 45 45 which Avg 0.077 0.043 0.227 0.118	is	betwe	27	and	28						
Spill_number Spill_betwee FS Hr Result	1 27 P 1 27 28 35 39 40 41 42 43 45 for J 27 56 39 40 43	28 P 0.99 27 28 35 39 40 41 43 45 5 5 8 5 0.008 0.231 0.095 0.203	P 0.97 27 28 35 39 40 43 45 45 MM 0.09 0.05 0.28 0.28 0.15 0.25	P 0.92 27 35 39 40 43 45 	P 0.85 27 39 40 43 45 45 which Avg 0.077 0.043 0.227 0.118 0.199	is	betwe	27	and	28						

Results

	Spill_number	2																							
	Spill_betweei	- 29	30																						
	FS	M	М	M	M	M	M	M	M	M	М	М	М	М	М	М	M	M	М	М	M	Р	M	M	
	Hr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.97	0.97	0.88	0.74
		27	27	27	27	27	27	27	27	27	27	27	28	28	28	28	28	28	28	28	29	29	29	29	29
		28	28	28	28	28	28	28	28	28	28	28	29	29	29	29	29	29	29	29	30	41	41	44	44
		29	29	29	29	29	29	29	29	29	29	29	30	- 30	30	30	30	30	30	- 30	41	43	44	46	75
		- 30	30	30	30	30	30	30	30	30	30	30	32	32	32	32	32	32	32	41	43	44	46	75	
-		31	31	31	31	31	31	31	31	31	32	32	39	40	40	40	40	41	41	43	44	46	75		
		32	32	32	32	32	32	32	32	32	38	39	40	41	41	41	41	42	43	44	46	75			
		33	33	33	35	35	35	35	37	38	39	40	41	42	42	42	42	43	44	46	75				
		34	34	35	36	36	37	37	38	39	40	41	42	43	43	43	43	44	46	75					
ľ		35	35	36	37	37	38	38	39	40	41	42	43	44	44	44	44	46	75						
ľ		36	36	37	38	38	39	39	40	41	42	43	44	45	45	46	46	75	_						
ľ		37	37	38	39	39	40	40	41	42	43	44	45	46	46	75	75								
ŀ		38	38	39	40	40	41	41	42	43	44	45	46	75	75	76									
ŀ		39	39	40	41	41	42	42	43	44	45	46	75	76	76										
ŀ		40	40	41	42	42	43	43	44	45	46	75	76	77											
ľ		41	41	42	43	43	44	44	45	46	75	76	77												
ľ		42	42	43	44	44	45	45	46	75	76	77													
ŀ		43	43	44	45	45	46	46	75	76	77														
		44	44	45	46	46	75	75	76	77															
ŀ		45	45	46	75	75	76	76	77																
ŀ		46	46	75	76	76	77	77																	
ŀ		74	75	76	77	77	80																		
ŀ		75	76	77	78	80																			
ŀ		76	77	78	80																				
ŀ		77	78	80																					
ŀ		78	80																						
		79																							
ŀ		80																							
											1			1											
-	Spill number	2																							
ľ	Spill betweer	29	30																						
	FS	M	М	М																					
ľ	Hr	1	1	0.84																					
ľ		28	29	29																					
		29	44	44																					
		44	46	75																					
ľ		46	75																						
ŀ		75																							
		. 2																							
ľ	Result	for	spill	numbe	2	which	is	betwe	29	and	30														
Ì		J	Ċ	MM	Pe	Avg																			
ľ		29	0.389	0.37	0.323	0.361	-		_																
		44	0.166	0.26	0.182	0.202																			
ľ		46	0.084	0.07	0.164	0.106																			
ľ		75	0.362	0.3	0.331	0.332																			
																								-4	-



Results	Spill_number Spill_betweer	3 31	33														
	FS	M	M	М	М	M	M	M	М	M	M	M	M	M	M	М	
	Hr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
		- 27	29	29	29	30	30	30	30	30	30	30	- 30	- 31	- 31	31	31
		28	30	30	30	31	31	31	31	31	31	31	31	46	46	- 77	
		- 29	31	31	31	33	33	33	33	33	33	33	46	- 76	- 77		
		- 30	33	33	33	41	43	43	43	44	46	46	76	- 77			
24		- 31	40	41	41	43	44	44	44	46	76	76	77				
<pre></pre>		32	41	42	43	44	46	6 46	46	76	77	77					
77		- 33	42	43	44	46	75	5 75	76	77	78						
25 23 26		- 34	43	44	46	75	76	i 76	77	78							
28		- 35	44	46	75	76	77	77	78								
29		- 36	46	75	76	77	78	78									
26		37	75	76	77	78	80	)									
• <u>•</u> <u>•</u>		38	76	77	78	80											
		- 39	77	78	80												
73 77 34		40	78	80													
74		41	80														
man 1 - 2 2		42															
<sup>15</sup> <sup>40</sup> 38 <sup>35</sup> <sup>35</sup> <sup>33</sup>		43															
		44															
		45															
3 76 4 <sup>4</sup> 4 <sup>4</sup> 45 80		46															
		- 74															
77 - 20		- 75															
		- 76															
		- 77															
		- 78															
		- 79															
		80															
															_		
	Result	for	spill	numb	3	which	is	betwe	31	and	33						
		J	С	MM	Pe	Avg											
		31	0.745	0.69	0.683	0.705	-										
		- 77	0.255	0.31	0.317	0.295											

<b>Results</b>	Spill_number Spill_betweei FS Hr	4 32 32 32 32 33 30 31 32 33 34 35 33 34 35 33 34 35 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 32 33 34 33 34 33 34 33 34 33 34 33 34 33 34 34	33 1 1 27 28 29 30 31 32 33 34 35 36 36 37 38 39 40 41 42 43 44 45 46 74 75 76 77 78 80	M 1 27 28 29 30 31 32 34 36 37 38 39 40 41 42 43 44 45 76 77 76 77 78 80	M 1 27 28 29 30 31 32 34 35 36 37 38 39 40 41 42 43 44 45 46 74 75 76 77 80 	M 1 27 28 29 30 31 32 34 35 36 37 38 39 40 41 42 43 44 45 46 75 76 77 80	M 1 27 28 29 30 31 35 36 36 37 38 39 40 41 42 43 44 45 46 75 76 77 80	M 1 27 28 29 30 31 35 35 35 35 35 37 38 39 40 41 42 43 44 45 75 76 77	M 1 27 28 29 30 32 35 36 37 38 39 40 41 41 42 43 44 5 46 75 76 77	M 1 27 28 29 30 32 35 37 38 39 40 41 42 43 44 5 5 76 77	M 1 27 28 29 30 32 35 37 38 39 40 41 42 43 44 45 75 76	M 1 27 28 29 30 32 37 38 39 9 40 41 42 43 44 45 75 76	M 1 27 28 29 30 32 38 39 40 40 41 41 42 43 44 45 75 5 76 76	M   1 27 28 29 30 32 38 39 40 41 41 42 43 44 45 46 75	M 1 27 28 29 30 32 39 40 41 41 42 43 44 45 75	M 1 27 28 29 32 39 40 41 42 43 44 45 46 75	P 0.98 27 28 29 32 40 41 42 43 43 44 45 46 75	M 0.97 27 28 29 32 40 41 43 44 45 46 75	M 0.97 28 29 32 40 41 43 44 5 46 75	P 0.93 28 29 32 40 41 43 44 75	P F 0.93 28 29 32 41 43 44 46 75 75 75	0.9 28 29 32 41 43 44 46 	D.82 28 29 32 41 44 46
	Spill_number Spill_betweer FS Hr Result	4 32 P P 1 28 29 32 40 41 43 44 43 44 46 50 50 50 50 50 50 50 50 50 50 50 50 50	33 0.99 28 29 32 41 43 44 46 	M 0.91 28 29 32 41 44 46 MM 0.06 0.11 0.03 0.35	M 0.91 28 29 32 41 44 44 Pe 0.103 0.074 0.119 0.164 0.164	M 0.76 28 29 41 44 44 0.061 0.075 0.061 0.075 0.06	is	betwee		and													



Spill	_number	5											
Spill	_betweer	- 33	80										
FS		M	M	IN	1	Р							
Hr		1		1	1	0	0						
-		- 27	33	3	- 33	79	79						
		- 28	- 78	3	- 79	80							
		- 29	- 79	9	80								
		- 30	80										
		31											
		32											
		33											
		34											
		35											
		- 36											
		37											
		- 38											
		- 39											
		40											
		41											
		42											
		43		_									
		44											
		45		_									
		46		_									
		/4											
		75											
		/b		_									
		70		-									
		70		-									
		79		-									
		80		-									
Resi	ult	for	spill	n	umbe	5	which	is	betwe	33	and	80	
		J	С	M	1M	Pe	Avg						
		- 79	- (	ו	0	1	0.5						
		80	(	וכ	1	0	0.5	←					



Spill_nun	nber	6												
Spill_bet	weer	35	45											
FS	F	P	Ρ	Р	Р	Ρ	Р	Р	Р	Р	Ρ	Р	Р	
Hr		1	1	1	1	1	1	1	1	1	0.98	0.96	0.89	0.81
		27	27	27	27	27	27	27	27	27	27	34	34	34
		28	28	28	28	34	34	34	34	34	34	35	35	35
		29	32	34	34	35	35	35	35	35	35	36	36	36
		30	34	35	35	36	36	36	36	36	36	37	37	37
		31	35	36	36	37	37	37	37	37	37	38	38	38
		32	36	37	37	38	38	38	- 38	38	38	42	42	
		33	37	38	38	39	39	39	40	42	42	74		
		34	38	39	39	40	40	40	42	43	74			
		35	39	40	40	41	42	42	43	74				
		36	40	40	40	42	43	43	74	17				
		37	40	42	47	42	45	74	14					
		38	42	42	42	45	74	14						
		30	42	40	40	4J 7A	74							
		40	4.0	44 AE	7/	74								
		40	44 AE	43	74									
		41	40	74										
		42	74											
		45												
		44												
		45												
		46												
		/4												
		75												
		76												
		78												
		79												
		80												
- ···														
Spill_nun	nber	6												
Spill_betv	wooi													
	WCCI	35	45	_										
FS	1	35 P	45 P	P										
FS Hr	1	35 P 1	45 P 0.93	P 0.84										
FS Hr	1	35 P 1 34	45 P 0.93 34	P 0.84 34										
FS Hr	1	35 P 1 34 35	45 P 0.93 34 35	P 0.84 34 35										
FS Hr		35 P 34 35 36	45 P 0.93 34 35 36	P 0.84 34 35 36										
FS Hr	1	35 P 34 35 36 37	45 P 0.93 34 35 36 37	P 0.84 34 35 36 37										
FS Hr		35 P 34 35 36 37 38	45 P 0.93 34 35 36 37 37 38	P 0.84 34 35 36 37 38										
FS Hr		35 P 34 35 36 37 38 42	45 P 0.93 34 35 36 36 37 38 42	P 0.84 34 35 36 37 38										
FS Hr		35 P 34 35 36 37 38 42 74	45 P 0.93 34 35 36 37 38 42	P 0.84 34 35 36 37 38										
FS Hr		35 P 34 35 36 37 38 42 74	45 P 0.93 34 35 36 37 38 42	P 0.84 34 35 36 37 38										
FS Hr		35 P 1 34 35 36 37 38 42 74	45 P 0.93 34 35 36 37 38 42	P 0.84 34 35 36 37 38										
FS Hr		35 P 1 34 35 36 37 38 42 74 74	45 P 0.93 34 35 36 37 38 42 	P 0.84 35 36 37 38	6	which	is	betwe	35	and	45			
FS Hr Result		35 P 1 34 35 36 37 38 42 74 74	45 P 0.93 34 35 36 37 38 42 42 spill C	P 0.84 35 36 37 38 	6 Pe	which	is	betwe	35	and	45			
FS Hr Result		35 P 1 34 35 36 37 38 42 74 74 	45 P 0.93 34 35 36 37 38 42 	P 0.84 34 35 36 37 38 	6 Pe 0.134	which Avg 0.147	is	betwe	35	and	45			
FS Hr Result		35 P 1 34 35 36 37 38 42 74 74 74 	45 P 0.93 34 35 36 37 38 42 spill C 0.132 0.219	P 0.84 34 35 36 37 38 	6 Pe 0.134 0.168	which Avg 0.147 0.179	is	betwe	35	and	45			
FS Hr Result		35 P 1 34 35 36 37 38 42 74 74 74 74 74 74 74 74 74 74 74 74 74	45 P 0.93 34 35 36 37 38 42 spill C 0.132 0.219 0.066	P 0.84 34 35 36 37 38 	6 Pe 0.134 0.082	which Avg 0.147 0.179	is	betwe	35	and	45			
FS Hr Result		35 P 1 34 35 36 37 38 42 74 74 74 5 74 34 35 36 37	45 P 0.93 34 35 36 37 38 42 Spill C 0.132 0.132 0.219 0.219 0.264	P 0.84 34 35 36 37 38 	6 Pe 0.134 0.188 0.082	which Avg 0.147 0.079 0.025	is 🗸	betwe	35	and	45			
FS Hr		35 P 1 34 35 36 37 38 42 74 74 74 5 5 36 37 38 34 35 36 37 32	45 P 0.93 34 35 36 37 38 42 spill C 0.132 0.219 0.219 0.066 0.224	P 0.84 34 35 36 37 38 	6 Pe 0.134 0.168 0.082 0.254	which Avg 0.147 0.179 0.095 0.243 0.254	is 🗸	betwe	35	and	45			
FS Hr Result		35 P 1 34 35 36 37 38 42 74 74 5 74 5 6 7 4 38 42 74 5 7 4 3 8 36 37 38 36 37 38 42 74	45 P 0.93 34 35 36 37 38 42 5 5 8 10 0 0.132 0.219 0.066 0.244 0.303 0.024	P 0.84 34 35 36 37 38 	6 Pe 0.134 0.082 0.254 0.28	which Avg 0.147 0.095 0.243 0.259 0.275	is	betwe	36	and	45			



Results

opin_number											
Spill_betweer	37	38									
FS	Р	Р	Р	Р	Р	Р	Ρ	M	Р	M	
Hr	1	1	1	1	1	1	1	0.99	0.93	0.89	0.83
	27	27	27	27	27	27	27	27	27	27	27
	28	28	28	34	34	34	34	34	34	34	34
	29	34	34	35	35	35	35	35	35	35	35
	30	35	35	36	36	36	36	36	36	36	37
	31	36	36	37	37	37	37	37	37	37	38
	32	37	37	38	38	38	38	38	38	38	42
	33	38	38	39	39	39	40	42	42	42	
	34	39	39	40	40	40	40	43	43	72	
	35	40	40	40	40	40	43	74			
	36	40	40	41	42	42	74	14			
	27	41	41	42	43	43	(4				
	- 30	42	42	40	40	/4					
	30	43	43	40	74						
	- 39	44	45	74							
	40	45	74								
	41	/4									
	42										
	43										
	44										
	45										
	46										
	74										
	- 75										
	- 76										
	- 77										
	- 78										
	- 79										
	79 80										
	79 80										
	79 80										
	79 80										
	79 80 7										
Spill_number Spill_betweer	79 80 7 37	38									
Spill_number Spill_betweel FS	79 80 7 37 M	38 M	P	P							
Spill_number Spill_betweer FS Hr	79 80 7 37 M	38 M 0.98	P 0.91	P 0.83							
Spill_number Spill_betweer FS Hr	79 80 7 37 M 1 27	38 M 0.98 27	P 0.91 27	P 0.83 34							
Spill_number Spill_betweei FS Hr	79 80 7 37 M 1 27 34	38 M 0.98 27 34	P 0.91 27 34	P 0.83 34 35							
Spill_number Spill_betweei FS Hr	79 80 7 37 M 1 27 34 35	38 M 0.98 27 34 35	P 0.91 27 34 35	P 0.83 34 35 37							
Spill_number Spill_betweel FS Hr	79 80 7 37 M 1 27 34 35 36	38 M 0.98 27 34 35 36	P 0.91 27 34 35 37	P 0.83 34 35 37 38							
Spill_number Spill_betweei FS Hr	79 80 7 37 M 1 27 34 35 36 36 37	38 M 0.98 27 34 35 36 36 37	P 0.91 27 34 35 37 38	P 0.83 34 35 37 38 42							
Spill_number Spill_betweer FS Hr	79 80 7 37 M 1 27 34 35 36 37 38	38 M 0.98 27 34 35 36 37 38	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42							
Spill_number Spill_betweei FS Hr	79 80 7 37 M 1 27 34 35 36 37 38 42	38 M 0.98 27 34 35 36 37 38 42	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42							
Spill_number Spill_betweei FS Hr	79 80 7 37 37 M 1 27 34 35 36 37 38 37 38 42 74	38 M 0.98 27 34 35 36 36 37 38 42	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42							
Spill_number Spill_betweei FS Hr	79 80 7 37 37 37 34 35 36 37 38 37 38 42 74	38 M 0.98 27 34 35 36 36 37 38 42	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42							
Spill_number Spill_betweei FS Hr	79 80 7 37 37 M 1 27 34 35 36 37 38 42 74	38 M 0.98 27 34 35 36 37 38 42	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42							
Spill_number Spill_betweei FS Hr	79 80 7 37 M 1 27 34 35 36 37 38 42 74	38 M 0.98 27 34 35 36 37 38 42	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42							
Spill_number Spill_betweei FS Hr Result	79 80 7 37 37 4 35 36 37 38 42 74 74	38 M 0.98 27 34 35 36 37 38 42 \$pill	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42	which		betwee	37	and		
Spill_number Spill_betweei FS Hr Result	79 80 7 37 37 34 35 36 37 38 42 74 5 for J	38 M 0.98 27 34 35 36 37 38 42 5 9 8 42 5 9 8	P 0.91 27 34 35 37 38 42	P 0.83 34 35 37 38 42 42 7 Pe	which	is	betwee	37	and	38	
Spill_number Spill_betweei FS Hr Result	79 80 7 37 37 34 35 36 37 38 42 74 74 6 0 7 4 27	38 M 0.98 27 34 35 36 36 37 38 42 5 5 8 42 5 0.018	P 0.91 27 34 35 37 38 42 	P 0.83 34 35 37 38 42 42 7 Pe 0.009	which Avg 0.099	is	betwee	37	and	38	
Spill_number Spill_betweer FS Hr Result	79 80 7 37 37 34 35 36 37 38 42 74 74 for J 27 34	38 M 0.98 27 34 35 36 37 38 42 5 9 8 42 5 0.018 0.09	P 0.91 27 34 35 37 38 42 42 	P 0.83 34 35 37 38 42 7 Pe 0.009 0.159	which Awg 0.099 0.098	is	betwee	37	and	38	
Spill_number Spill_betweer FS Hr Result	79 80 7 37 37 34 35 36 37 38 42 74 5 6 0 J 27 34 35	38 M 0.98 27 34 35 36 37 38 42 5 9 10 C 0.018 0.09 0.22	P 0.91 27 34 35 37 38 42 numbe MM 0.27 0.05 0.27	P 0.83 34 35 37 38 42 7 Pe 0.009 0.159 0.162	which Avg 0.099 0.098 0.217	is		37	and	38	
Spill_number Spill_betweer FS Hr Result	79 80 7 37 37 34 35 36 37 38 42 74 5 6 7 4 5 7 4 38 37 7 4 35 37	38 M 0.98 27 34 35 36 37 38 42 42 0.018 0.09 0.22 0.255	P 0.91 27 34 35 37 38 42 numbe MM 0.27 0.05 0.027 0.05 0.27 0.1	P 0.83 34 35 37 38 42 7 Pe 0.009 0.159 0.162 0.292	which Awg 0.098 0.217 0.216	is		37	and		
Spill_number Spill_betweei FS Hr Result	79 80 7 37 37 34 35 36 37 38 36 37 38 42 74 74 74 74 74 35 37 38 37 38 37 38 37 38 37 38 37 38 37 38 37 38 37 38 37 38 37 38 38 37 37 37 37 37 37 37 37 37 37 37 37 37	38 M 0.98 27 34 35 36 37 38 42 5 8 9 0.25 0.255 0.339	P 0.91 27 34 35 37 38 42 numbe MM 0.27 0.05 0.27 0.27 0.27 0.27 0.27	P 0.83 34 35 37 38 42 7 Pe 0.09 0.159 0.159 0.292 0.281	which Avg 0.099 0.216 0.216 0.283	is	betwee	37	and		

<b>Results</b>	Spill_number Spill_betweer FS Hr	8 43 P 1 27 28 29 30 31 32 33 34 35 36 37 37 38 39 40 41 42 43 40 41 42 43 44 45 46 74 75 76 77 78 79 80	44 P 1 27 28 29 30 32 34 35 36 37 38 36 37 38 39 40 41 42 43 44 45 46 74 75 76	P 1 27 28 29 30 32 34 35 36 37 38 39 40 41 42 43 44 45 46 74 75	P 1 27 28 29 32 34 35 36 37 38 39 40 41 42 43 44 45 46 74 75	P 1 27 28 29 32 34 35 36 37 38 39 40 41 42 43 44 45 46 74	P 1 27 28 29 32 34 35 36 37 38 39 40 41 42 43 44 45 74	M 0.89 27 28 32 34 35 36 37 38 39 40 41 41 42 43 44 45 74	M 0.89 27 28 32 34 35 36 37 38 39 40 41 41 42 43 44 45	M 0.89 27 28 32 36 37 38 39 40 41 42 43 44 45	M 0.89 27 28 32 35 37 38 39 40 41 42 43 44 45	M 0.89 27 28 32 37 38 39 40 41 42 43 44 45 	M 0.89 27 28 32 38 39 40 41 42 43 44 45 	M 0.89 27 28 32 39 40 41 42 43 44 45 	M 0.89 27 28 32 40 41 42 43 44 45	M 0.89 28 32 40 41 42 43 44 45 	P 0.83 28 32 40 41 42 43 44 43 44	M 0.79 28 32 40 41 42 43 	M 0.74 28 32 40 41 43 	M 0.67 28 32 41 43 	
	Spill_number Spill_betweer FS Hr Result	79 80 8 43 M 1 28 32 41 43 6 0 J 28 32 41 43 28 32 41 43	44 P 0.76 28 41 43 5 5 0.129 0.129 0.191 0.565 0.115	numbe MM 0.11 0.65 0.15	8 Pe 0.27 0.412 0.266 0.053	which Avg 0.169 0.233 0.493 0.105	is	betwe	43	and	44										

	Dobut Derweel	( 70)	/61																				
6	FS	P F	2	P F	) P	•	P	Ρ	P F	>	P F	) F	<b>)</b>	P	P F	<b>)</b>	P I	P	Р	Р	Р	Р	Р
	Hr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.93
		27	27	27	27	27	27	27	27	27	27	27	28	28	28	28	28	28	28	28	29	29	29
		28	28	28	28	28	28	28	28	28	28	28	29	29	29	29	29	29	- 29	29	- 30	- 30	30
		29	29	29	29	- 29	29	29	29	29	29	29	30	30	30	30	- 30	- 30	- 30	- 30	32	44	46
		30	30	30	30	30	30	30	30	30	30	30	32	32	32	32	32	32	32	32	44	46	75
		31	31	31	31	31	31	31	31	31	31	32	35	39	40	40	40	41	41	44	46	75	76
		32	32	32	32	32	32	32	32	32	32	35	39	40	41	41	41	43	44	46	75	76	
		33	33	34	34	35	35	35	35	35	35	39	40	41	43	43	43	44	46	75	/6		
		34	34	35	35	36	3/	37	38	38	39	40	41	43	44	44	44	46	75	76			
		35	35	36	36	37	30	38	39	39	40	41	43	44	45	40	46	75	76				
		20	30 27	37	37	20	39	39	40	40	41	43	44	40	40	70	70	70					
		38	38	30	30	40	40	40	41	41	43	44	40	75	75	70	70						
26		39	39	40	40	40	41	41	42	43	44	45	75	76	70								
20		40	40	40	40	42	-+2 43	43	44	45	46	75	76	77	r r								
oq.		41	41	42	42	43	44	44	45	46	75	76	77										
		42	42	43	43	44	45	45	46	75	76	77											
		43	43	44	44	45	46	46	75	76	77												
<u>\</u>		44	44	45	45	46	74	75	76	77													
30		45	45	46	46	74	75	76	77														
		46	46	74	74	75	76	77															
		74	74	75	75	76	- 77																
<b>~_</b> 31		75	75	76	76	- 77																	
<u></u>		76	76	77	77																		
~ 3		77	- 77	78																			
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~		78	78																				
39 4		79																					
		80																					
~~~ <u>*</u> <sup>*</sup> ~ ~ <u>*4</u> 45 ~ <u>*</u> 80																							
145 79 00 79 79 00 70 79 00	 Spill_number	9																					
730°5~		9	76																				
79 80 79 79 80 79	Spill_number Spill_betwee FS	9 75 P F	76	P																			
7900 7900 70	Spill_number Spill_betwee FS Hr	9 75 P F	76 0.93	P 0.8																			
20 79 79 79 79 79 79	Spill_number Spill_betwee FS Hr	9 75 P F 1 29	76 0.93 29	P 0.8 30																			
20 79 79 79 79 79 79 79	Spill_number Spill_betwee FS Hr	9 75 P F 1 29 30	76 0.93 29 30	P 0.8 30 46																			
79 80 79 79 80 70	Spill_number Spill_betwee FS Hr	9 75 P F 1 29 30 44	76 0.93 29 30 46	P 0.8 30 46 75																			
79 445 79 80 79 79 80 79 79 80	Spill_number Spill_betwee FS Hr	9 75 P F 1 29 30 30 44	76 0.93 29 30 46 75	P 0.8 30 46 75 76																			
79 79 79 79 79 79 79 79 79 79 79 79 79 7	Spill_number Spill_betwee FS Hr	9 75 P F 29 30 44 46 75	76 0.93 29 30 46 75 76	P 0.8 30 46 75 76																			
75 - 20 77 - 20 77 - 20	Spill_number Spill_betwee FS Hr	9 75 P F 29 30 44 46 75 76	76 0.93 29 30 46 75 76	P 0.8 30 46 75 76																			
79 79 80 79 79 80 79 79 80	Spill_number Spill_betwee FS Hr	9 75 P F 29 30 44 46 75 76	76 0.93 29 30 46 75 76	P 0.8 30 46 75 76																			
7900 7900 700 700 700 700 700 700 700 70	Spill_number Spill_betwee FS Hr	9 75 P F 1 29 30 44 46 75 76 76	76 0.93 29 30 46 75 76	P 0.8 30 46 75 76																			
20 79 79 79 79 79 79 79 79 79 79 79 79 79	Spill_number Spill_betwee FS Hr Result	9 75 P F 1 29 30 44 46 75 76 76 76	76 0.93 29 30 46 75 76	P 0.8 30 46 75 76 76	9 w	hich	is	betwe	75 a	and	76												
20 79 79 79 79 79 79 79 79	Spill_number Spill_betwee FS Hr Result	9 75 P F 1 29 30 44 46 75 76 76 76 5 76 5 76 5 76	76 0.93 29 30 46 75 76	P 0.8 30 46 75 76 76 numbe	9 w	rhich wg	is	betwe	75 a	and	76												
79 80 79 80 79 80 79 80	Spill_number Spill_betwee FS Hr Result	9 75 P F 1 29 30 4 46 75 76 76 76 76 76 76 76 76 76 76	76 0.93 29 30 46 75 76 76	P 0.8 30 46 75 76 76 10 10 10 10 10 10 10 10 10 10 10 10 10	9 w 9 c 0.046 (0	hich wg 0.113	is	betwe	75 a	and	76												
20 20 20 20 20 20 20 20 20 20 20 20 20 2	Spill_number Spill_betwee FS Hr Result	9 75 P F 1 29 30 44 46 75 76 76 76 76 76 76 76 76 76 76 76 76 76	76 0.93 29 30 46 75 76 9 9 9 10 0.143 0.402 0.143 0.402	P 0.8 30 46 75 76 76 MM F 0.15 0.25	9 w 9 e 0.046 ( 0.308 ( 0.308 (	which wg 0.113 0.331	is	betwe	75 a	and	76												
20 20 20 20 20 20 20 20 20 20 20 20 20 2	Spill_number Spill_betwee FS Hr Result	P F 1 29 30 44 46 75 76 76 5 76 1 29 30 4 4 4 4 6 75 7 6 7 6 7 6 7 6 7 6 7 7 6 7 7 7 7 7 7 7 7 7 7 7 7 7	76 0.93 29 30 46 75 76 0.143 0.402 0.143 0.402 0.125 0.022	P 0.8 30 46 75 76 76 8 8 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9	9 w Pe A 0.046 ( 0.308 ( 0.192 ( 0.071 (	wich wg 0.113 0.331 0.188	is	betwe	75 a	and	76												

\_74

## Results

Spi	ll_number	10														
Spi	ll_betweer	- 77	78													
FS		M	M	M	M	M	M	M	M	M	M	M	M	M	М	
Hr		1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
		- 27	29	29	30	- 30	30	- 30	- 30	- 30	31	- 31	- 31	31	31	31
		28	30	30	31	31	31	31	31	- 31	- 33	- 33	- 33	- 33	- 77	
		- 29	31	31	33	33	33	- 33	- 33	- 33	46	46	- 77	- 77		
		- 30	33	33	41	41	43	44	- 44	46	- 76	- 77	- 78			
		- 31	41	41	43	43	44	46	46	- 76	- 77	- 78				
		32	42	43	44	44	46	- 76	- 76	- 77	78					
		- 33	43	44	46	46	76	- 77	- 77	- 78						
		- 34	44	46	75	76	77	- 78	- 78							
		- 35	46	75	76	77	78	80								
		- 36	75	76	- 77	78	80									
		- 37	76	77	78	80										
		- 38	77	78	80											
		- 39	78	80												
		40	80													
		41														
		42														
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		- 45														
		- 46														
		- 74														
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		- 79														
		80														
Res	sult	for	spill	numbe	10	which	is	betwe	77	and	78					
		J	Ċ	MM	Pe	Avg										
		31	0.954	0.93	0.699	0.86										
		77	0.040													

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## Conclusions

- Modified ASFS algorithm performed well for both regions tested by total of 20 spill events.
  - •The correct answer was kept in final sets for all 20 spill events.
  - The worst performance was reducing initial class set of 26 elements to a final selected set of 7 elements.
  - The best performance was reducing the initial class set of 27 elements to a final selected set of 2 elements.
- Final set is ranked according to the average of posterior conditional probabilities obtained for each single feature and joint behavior of the two.
- Once the statistical data is obtained from simulations (takes about 2 weeks), this method is fast (takes about 30 seconds to analyze all 20 spills).





