

Report Documentation Page

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Air Force Institute Of Technology

Feasibility Study of Variance Reduction in the THUNDER Campaign Level Model

Capt Earl M. Bednar

**Military Operations Research Society
Symposium**

22 June 2005



Educating The World's Best Air Force!



Overview



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- Objective
- THUNDER
- Methodology
- Analysis
- Conclusions



Objective



- Problem:
 - Chief of Staff of the Air Force (CSAF)
 - Air Force Studies and Analysis Agency (AFSAA)
 - Request an effective & efficient method to reduce the variance in the results of THUNDER
- Answer:
 - Control Variates
 - Common Random Numbers
 - Antithetic Variates



THUNDER



- Air Force Standard Analysis Toolkit (AFSAT)
- Campaign-level joint military operations
- Written in CACI's SIMSCRIPT II.5
 - English like programming language
- >1,500 source files
- >360,000 lines of code
- 254 random inputs



Overview



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- **Methodology**
 - **Common Random Numbers**
 - **Control Variates**
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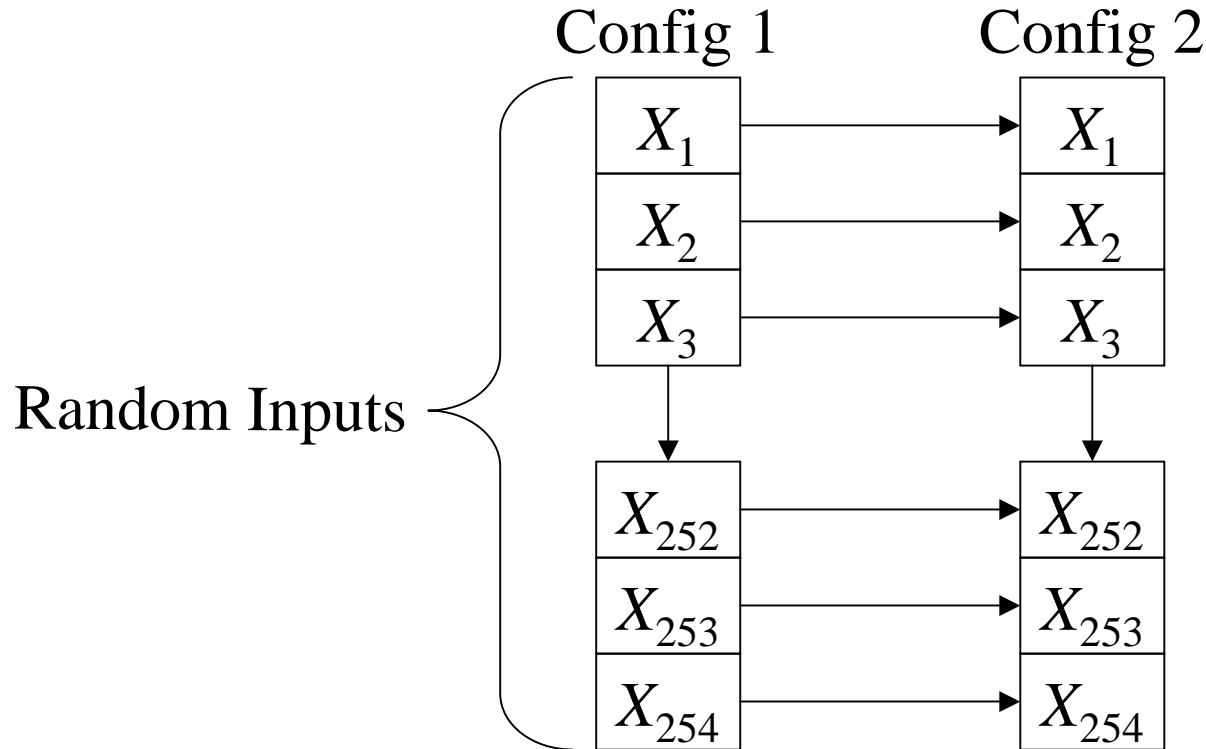


Common Random Numbers



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- Synchronization



- Problem with current RNG

- 254 random variates and only 10 streams



Random Number Generator



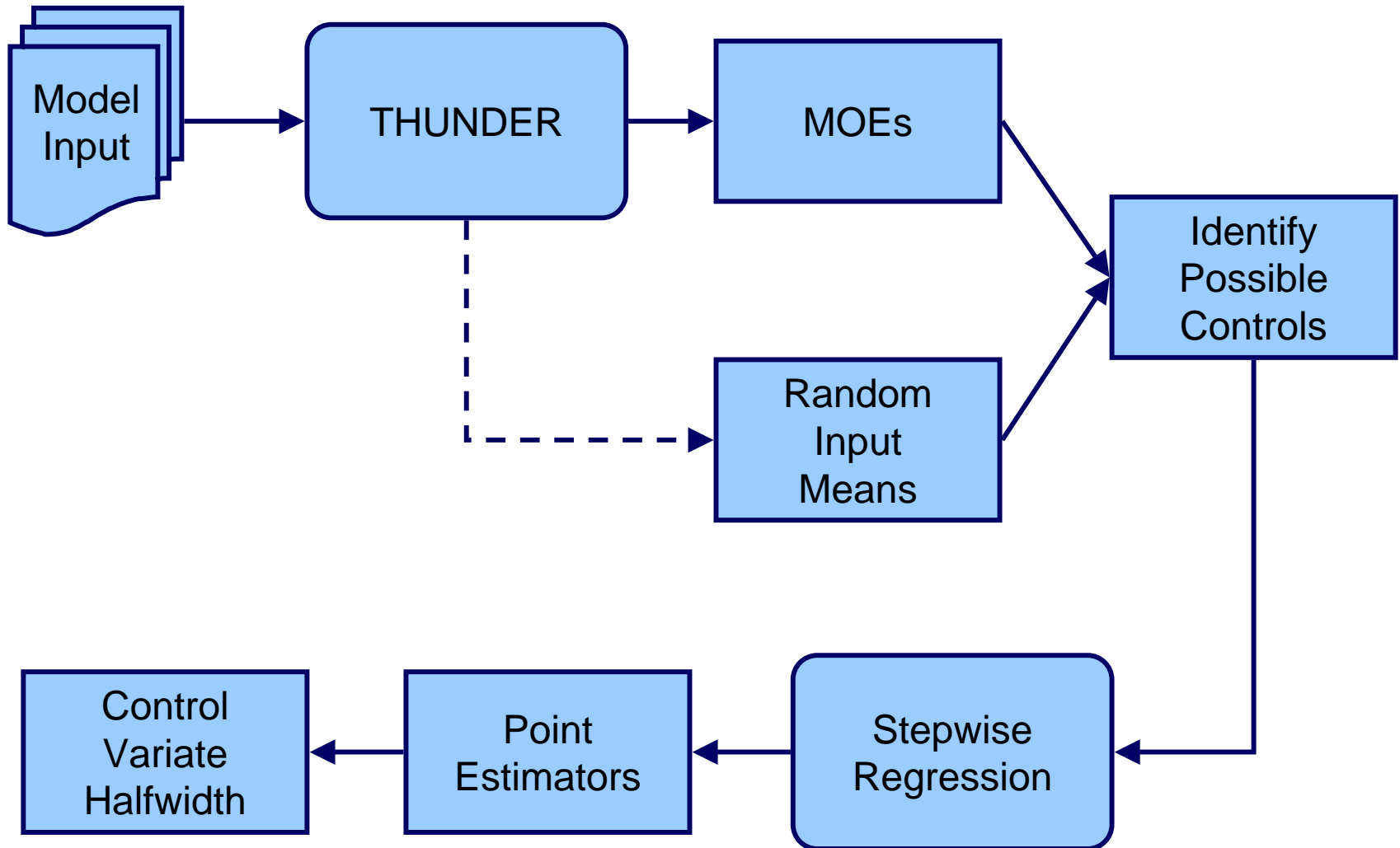
- MRG32k3a
- Developed by
 - Pierre L'Ecuyer
 - U. de Montréal
 - Richard Simard
 - U. de Montréal
 - E. Jack Chen
 - BASF Corp.
 - W. David Kelton
 - U. of Cincinnati
- Linear Congruential Generator
 - period 1.6×10^7 to 2.8×10^{14} elements
- Combined Multiple Recursive Generator
 - 1.8×10^{19} streams
 - 1.7×10^{38} elements
- Programmed in C and Java
 - Streams, Antithetics, Seeds



Control Variates Flow Chart



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 - **Control Variates**
 - **Random Number Generator**
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Measures Of Effectiveness



- 20 MOEs
 - Flown per Planned Sortie
 - Losses per Sortie
 - Square Miles Gained
- 4 Levels of Aggregation
 - Force
 - Base
 - Squadron
 - System



Experimental Runs



- 8 separate run configurations
 - 30 Replications each
 - 240 Total Replications
 - ASC Major Shared Resource Center

	RNG	SYNCHRONIZED	ANTITHETIC	COLLECT CV	CONFIGURATION
SET	(NEW/OLD)	(YES/NO)	(YES/NO)	(YES/NO)	(ORIGINAL/MODIFIED)
A	OLD	NO	NO	YES	ORIGINAL
B	NEW	NO	NO	NO	ORIGINAL
C	NEW	NO	NO	YES	MODIFIED
D	NEW	YES	NO	YES	ORIGINAL
E	NEW	YES	NO	YES	MODIFIED
F	NEW	YES	YES	YES	ORIGINAL
G	OLD	NO	NO	NO	ORIGINAL
H	NEW	YES	NO	NO	ORIGINAL



Common Random Numbers



- Reduction
 - 10 of 19
- No patterns

MOE	BASE HALFWIDTH	SYNCHRONIZED HALFWIDTH	PERCENT CHANGE
A-10 LPS	0.001940153	0.001590769	-18.01%
A-6 LPS	0.005187968	0.003856901	-25.66%
BLUE FPS	0.010247512	0.008539409	-16.67%
BLUE LPS	0.000770395	0.000659791	-14.36%
BLUE SMG	401.9576399	357.5307451	-11.05%
DHAHRAN FPS	0.029904287	0.027359177	-8.51%
F-15 LPS	0.001401777	0.001609386	14.81%
FA-18 FPS total	0.016106877	0.01672975	3.87%
FA-18 FPS DCA	0.005501239	0.004594474	-16.48%
MIG-23 LPS	0.032332763	0.024092911	-25.48%
MIG-29 LPS	0.027652343	0.030965238	11.98%
MIRAGE FPS total	0.017106674	0.025227701	47.47%
MIRAGE FPS INT	0.029598399	0.030482717	2.99%
MIRAGE LPS	0.01957014	0.015011175	-23.30%
MUDAYSIS FPS	0.016871397	0.017668922	4.73%
RED FPS	0.006272345	0.006833599	8.95%
RED LPS	0.005909479	0.007268262	22.99%
RIYADH FPS	0.006359085	0.005819308	-8.49%
SHAIBAH FPS	0.034021777	0.040368895	18.66%



Control Variates



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MOE	REPLICATION HALFWIDTH	CV HALFWIDTH	PERCENT CHANGE	EQUIVALENT REPLICATIONS
A-10 LPS	0.00075445	0.000159564	-78.85%	607
A-6 LPS	0.003489524	0.002120285	-39.24%	77
BLUE FPS	0.009062548	0.007242324	-20.09%	46
BLUE LPS	0.000561401	0.00033589	-40.17%	79
BLUE SMG	268.0705303	236.1766719	-11.90%	38
DHAHRAN FPS	0.031932469	0.024634985	-22.85%	49
F-111 LPS	0.001710663	0.000817956	-52.18%	121
F-15 LPS	0.000969011	0.000627455	-35.25%	68
FA-18 FPS total	0.016933126	0.015413409	-8.97%	36
FA-18 FPS DCA	0.003428121	0.003311208	-3.41%	32
MIG-23 LPS	0.020114382	0.020331007	1.08%	30
MIG-29 LPS	0.026351157	0.022059499	-16.29%	42
MIRAGE FPS total	0.015716995	0.013363553	-14.97%	41
MIRAGE FPS INT	0.022547304	0.013958327	-38.09%	74
MIRAGE LPS	0.014436042	0.013046527	-9.63%	37
MUDAYSIS FPS	0.013106485	0.012044326	-8.10%	35
RED FPS	0.004319957	0.003268615	-24.34%	51
RED LPS	0.005896852	0.005145653	-12.74%	39
RIYADH FPS	0.006054193	0.004081502	-32.58%	63
SHAIBAH FPS	0.022973304	0.016907879	-26.40%	53



Control Variates



MOE	WEIGHT	CONTROL	MOE	WEIGHT	CONTROL
A-10 LPS	-0.0002	AIR060_2	MIG-23 LPS	-6.6526	ADF121_2
A-6 LPS	-0.0071	AIR050_2		0.1433	AIR101_1
BLUE FPS	-0.0759	ISR000_4	MIG-29 LPS	0.6471	AIR528_1
	-0.0722	AIR050_1		-1.4314	BSE050_1
	-0.0659	AIR070_2		-0.2311	GRD095_1
	-0.0035	AIR800_3		-0.7147	ISR000_4
	0.3282	BSE400_1	MIRAGE FPS total	-0.3242	ADF150_1
	46.8237	PLA443_1	0.5198	AIR561_1	
	0.6659	UTL104_1	0.0855	AIR602_1	
BLUE LPS	0.0101	ADF150_2	MIRAGE FPS INT	-3.3544	ADF121_1
BLUE SMG	-23825.1823	ADF105_1	7.9362	ADF121_2	
	40.5388	AIR060_2	0.0101	AIR800_3	
	3649.5981	AIR101_2	-1.0679	BSE003_2	
	-1408.6753	AIR561_2	106.4336	PLA443_1	
	-20765.0668	AIR840_1	MIRAGE LPS	-2.3615	ADF121_1
	-27766.1967	AIR840_2	MUDAYSIS FPS	-0.2438	ADF150_2
	-8446.2005	BSE400_1	-0.0089	AIR800_3	
DHAHRAN FPS	-0.1779	AIR050_1	0.1621	GRD095_2	
	-0.2230	AIR070_2	RED FPS	0.6949	BSE200_5
	0.9677	BSE400_1	RED LPS	0.0922	ADF150_1
F-111 LPS	0.0213	ADF150_2	-0.0629	AIR070_2	
	-0.0120	AIR060_1	0.6117	UTL104_1	
	-0.1221	BSE200_5	RIYADH FPS	-0.2501	AIR007_1
F-15 LPS	0.0069	AIR050_1	-0.0395	AIR101_1	
	0.0019	AIR050_2	-0.0621	AIR101_2	
FA-18 FPS total	0.0252	AIR050_2	-0.0505	GRD095_1	
	-0.0889	AIR070_2	SHAIBAH FPS	-0.1675	AIR101_1
	-1.3057	AIR810_2	1.3115	BSE003_1	
FA-18 FPS DCA	1.4195	ADF121_3			
	0.0006	AIR060_2			



BLUE Square Miles Gained



CONTROL	WEIGHT	MODULE PURPOSE	SPECIFIC DRAW PURPOSE
ADF105_1	-23825.18	Used to calculate the flight groups position, altitude, speed, average location, and delivery profile.	Used to check for point on battlefield. $.INTERVIS.ANGLE = (Distribution) / RADIAN.C$
AIR060_2	40.54	Manages defensive anti tactical ballistic missile mission detections and engagements.	Used in setting saturation delay on shooter. (Distribution)
AIR101_2	3649.60	Sets up and air engagement by creating and air-to-air engagement for each flight to be used for storing computations.	Used in determining the engagement probability. $(.prob.engage < U(0,1))$
AIR561_2	-1408.68	Determines if, having arrived at the target's estimated coordinate, the flight group can find the target.	Determines the success of a mid-course update. $(U(0,1) \leq .best.prob)$
AIR840_1	-20765.07	Determines the number of target elements that are destroyed when a given weapons area of effect fully or partially covers a target.	Determine whether a live target element is hit. $(U(0,1) < .prob.hit.live)$
AIR840_2	-27766.20	Determines the number of target elements that are destroyed when a given weapons area of effect fully or partially covers a target.	Determine whether a live target element is hit. $(U(0,1) < .exp.live.hits)$
BSE400_1	-8446.20	Determine s the availability of aircraft, establishes the munition configurations, allocates fuels and determines whether to cancel or run the mission as scheduled.	Determines the cancellation of a sortie due to degrade. $(U(0,1) < eawp.sortie.degrade)$



Random Number Generator

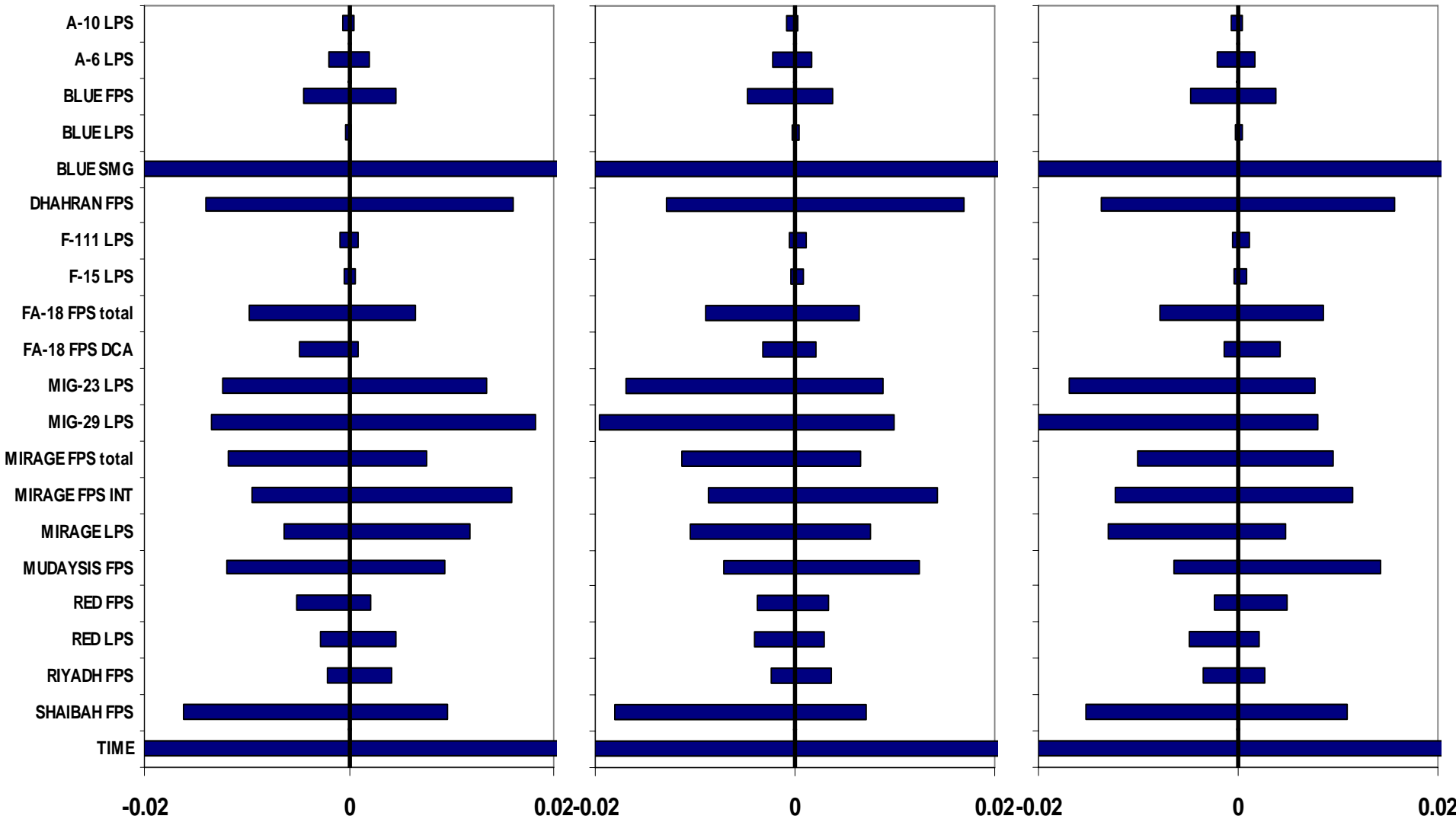


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**Original vs.
New (not synchronized)**

**Original vs.
New (synchronized)**

**New (not synchronized) vs.
New (synchronized)**





Overview



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Conclusions



- Common random numbers
 - Generally synchronize
 - Need new random number generator
 - Will not always result in reduction
- Control variates
 - Always reduction
 - Better estimates with less replications
 - Good insight
 - Able to be automated
- Both methods are applicable to STORM



QUESTIONS?



Thank You

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