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THE DEPARTMENT OF AERONAUTICAL AND AUTOMOTIVE ENGINEERING

SYSTEMS, RISK AND RELIABILITY GROUP

Safety System Optimization By Improved Strength Pareto Evolutionary Approach (SPEA2)

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1 Introduction

A safety system is an essential part of an industrial system as it operates to prevent the occurrence of certain conditions and their future development into a hazardous situation.

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2 Aim of Work

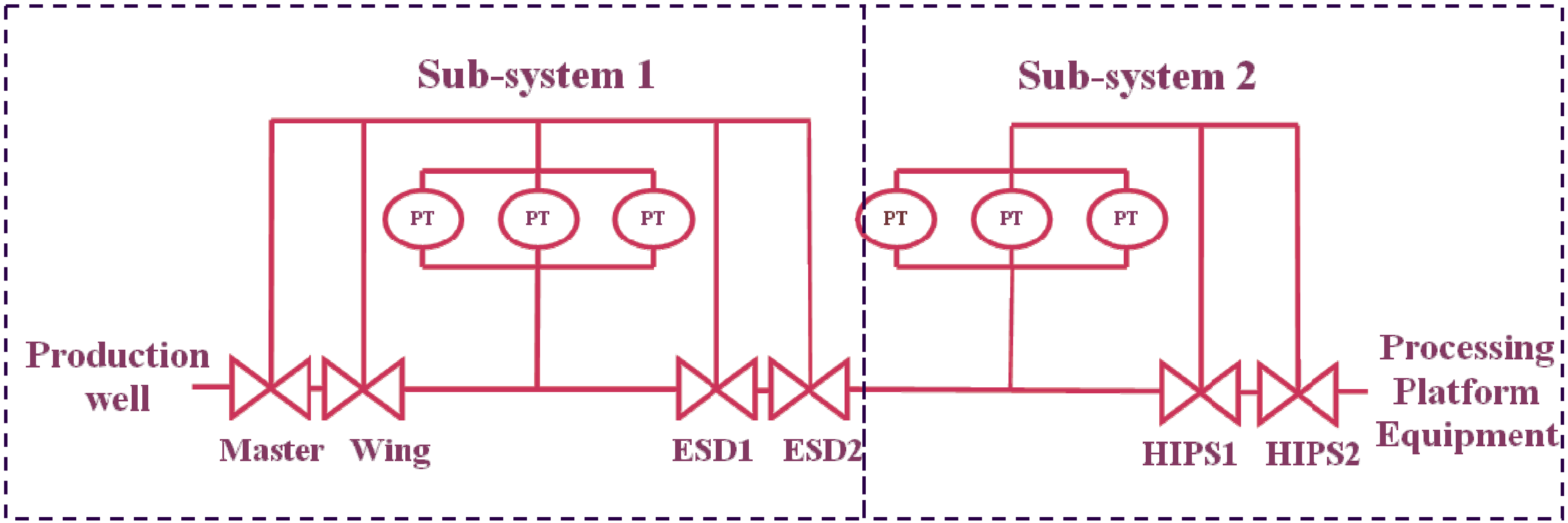
To investigate a design optimisation scheme which yields an optimal safety system design by fully utilizing available resources.

3 Optimization Criteria

- Unavailability
- Cost
- Spurious trip frequency
- Maintenance down time

4.1 The HIPS System

General Structure of the High Integrity Protection System (HIPS):



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4.2 The HIPS System

Variable	Description	Value
θ_1, θ_2	Inspection intervals for subsystems 1 and 2	1 week – 2 years
V	Valve type	1 or 2
P	Pressure transmitter type	1 or 2
N_1, N_2	Number of pressure transmitters fitted in subsystem 1 and 2 respectively	1 – 4 0 – 4
K_1, K_2	Number of pressure transmitters required to trip (activate) for subsystem 1 and 2 respectively	$1 - N_1$, $0 - N_2$
E	Number of ESD valves fitted	0, 1, 2
H	Number of HIPS valves fitted	0, 1, 2

Main HIPS Variables

4.3 The HIPS System

Limitation	Maximum Value
Total system cost (COST)	< 1000 units
Maintenance down-time (MDT)	< 130 hours
System spurious failure frequency (Fsys)	1 time per year

HIPS Design Limitations

5 Optimization Technique

Fault Tree Analysis

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Binary Decision Diagrams

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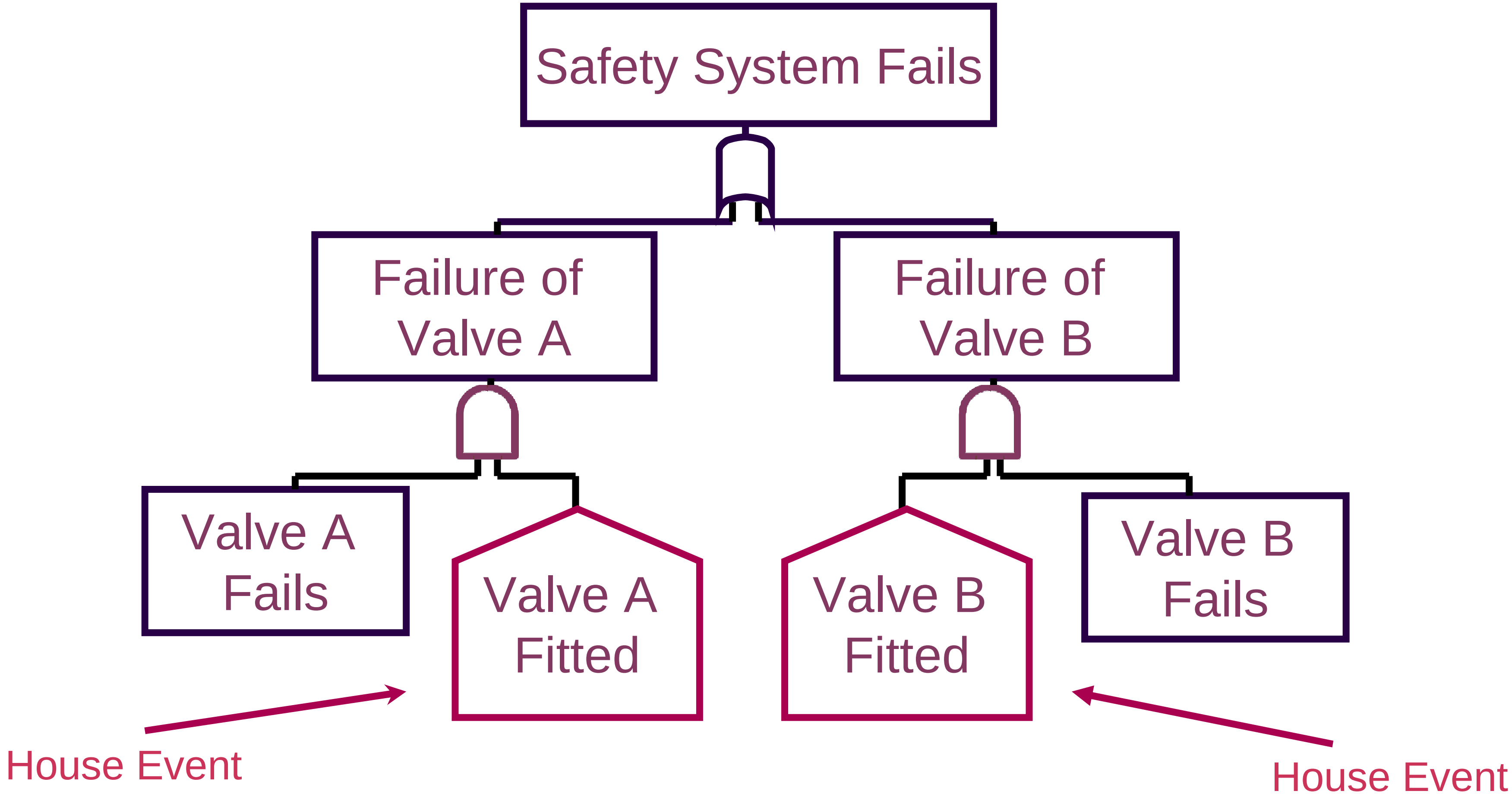
Improved Strength Pareto Evolutionary Approach (SPEA2)

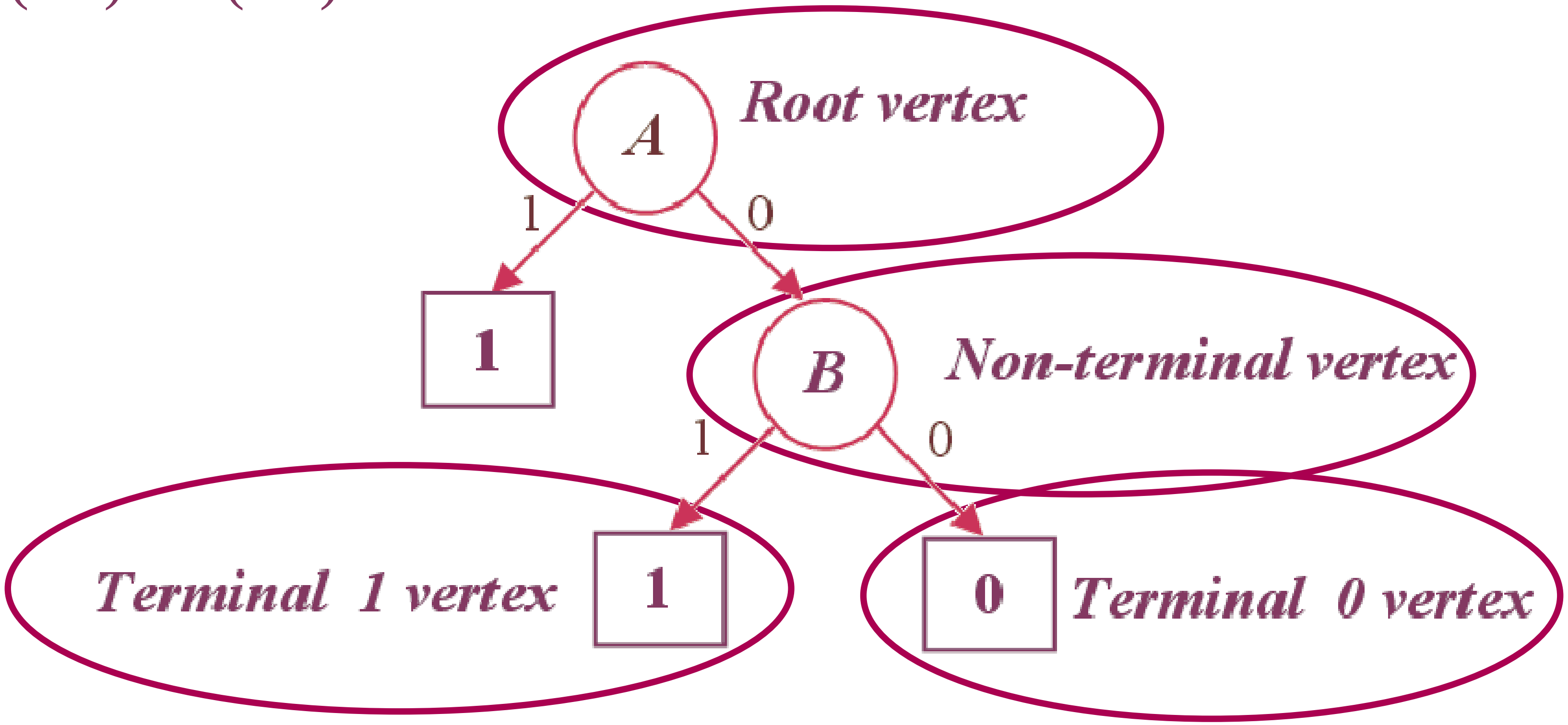
6 Fault Tree Analysis



Example of the Fault Tree with House Events

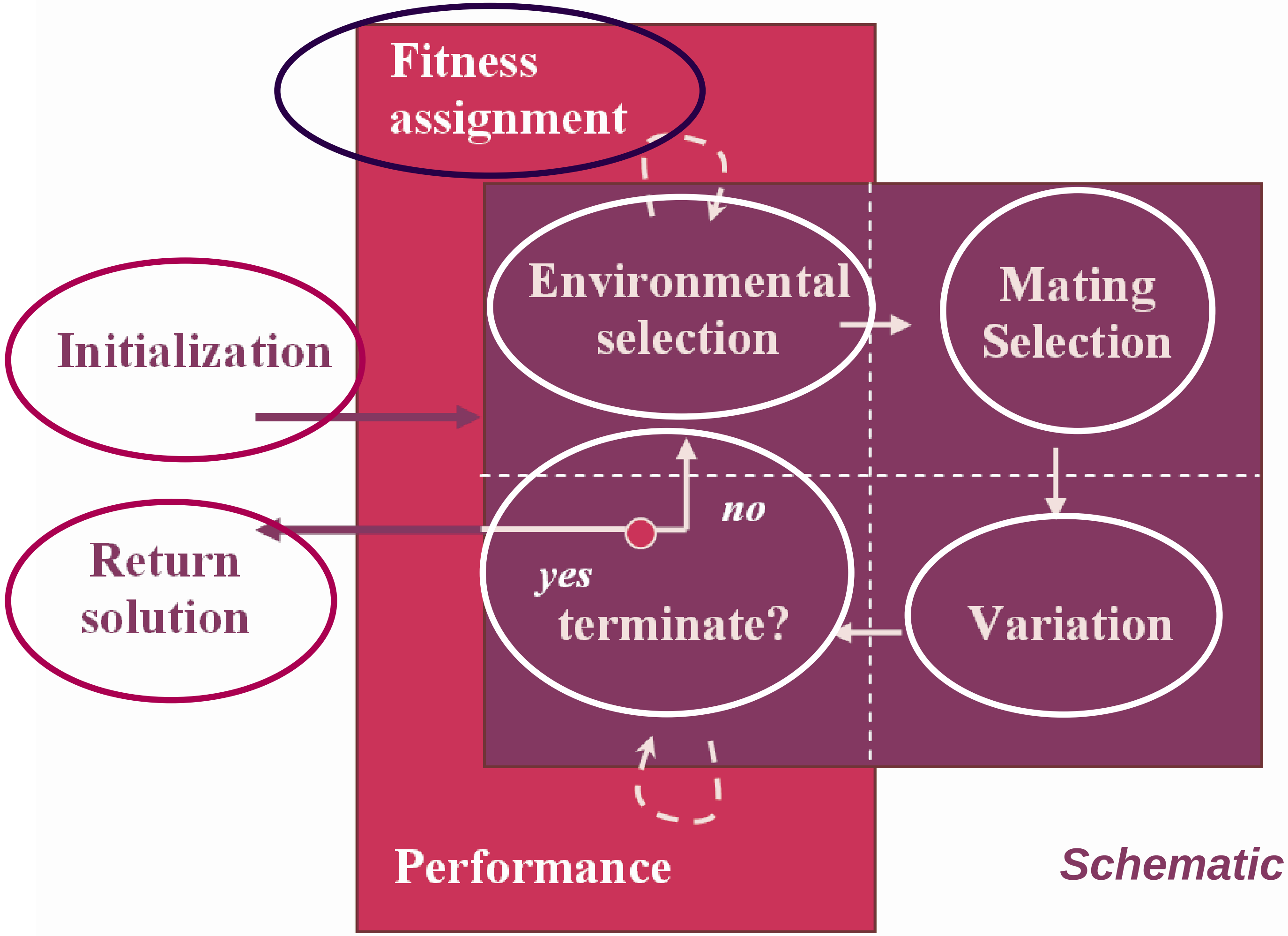
7 Binary Decision Diagrams

If P(H1) = P(H2) = 1



Example BDD

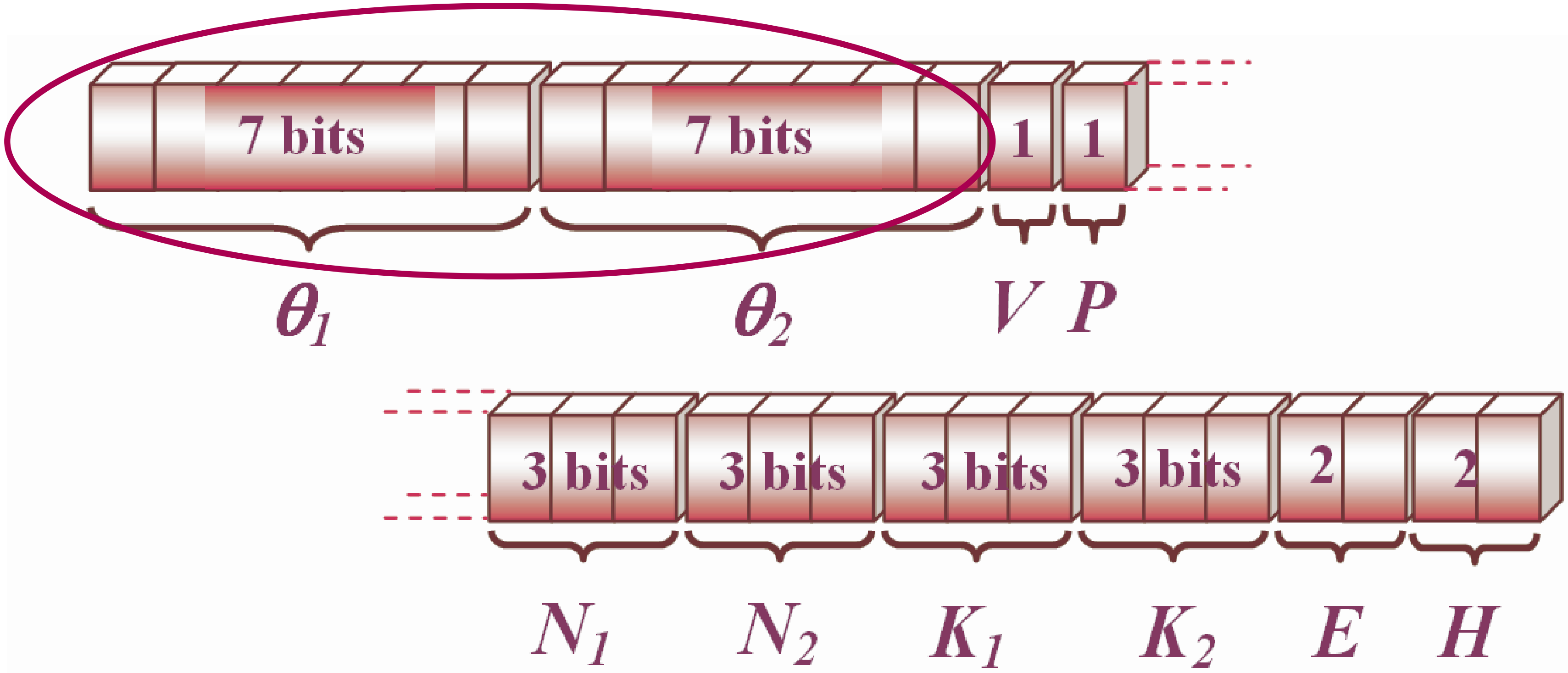
8 SPEA2 Algorithm



Schematic of the SPEA2

9.1 SPEA2 Implementation

Coding and Initializing the Population:



Total length = 32 bits

9.2 SPEA2 Implementation

Optimization Parameters Evaluation:

- Cost = Cost(subsystem1)+Cost(subsystem2) < 1000 (1)
- MDT = MDT(subsystem1)+MDT(subsystem2) < 130 (2)
- Penalized Qsys = Qsys + Penalties (3)

where

Penalties = Cost_pen + MDT_pen +Spurious_trip_pen

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10.1 Results

Run No.	Cost	MDT	F_{sys}	Q_{sys}
1	592	129.7008	0.455	4.5e-7
2	512	129.6974	0.332	8.33e-4
3	582	128.7361	0.324	6.8e-4
4	922	128.2273	0.718	1e-6
5	882	129.1590	0.166	1e-6
6	992	129.2523	0.552	1e-6
7	852	128.3286	0.245	6.55e-4
8	542	128.9881	0.324	8.45e-4
9	872	129.9032	0.377	1e-6
10	862	129.7309	0.999	1e-6
Average values	**761**	**129.1724**	**0.449**	**3.01e-4**

Fittest Designs after 10 Runs of SPEA2 Program (100 generations each)

10.2 Results

		GAs	SPEA2
Subsystem 1	No. of ESD valves (E)	0	0
	No. of PTs (N_1)	2	1
	No. of PTs to trip system (K_1)	1	1
	Maintenance test interval (θ_1)	29	25
Subsystem 2	No. of HIPS valves (H)	2	1
	No. of PTs (N_2)	3	3
	No. of PTs to trip system (K_2)	2	3
	Maintenance test interval (θ_2)	32	73
Valve type (V)		2	1
PT type (P)		1	2
MDT		**128.43**	**129.7008**
Cost		**822**	**592**
Spurious trip occurrence (F_{sys})		**0.717**	**0.455**
System unavailability (Q_{sys})		**7.6e-4**	**4.5e-7**

Results Comparison

11 Conclusions

- The proposed technique has been successfully applied to a high integrity protection system (HIPS) and produced better results for system design optimization comparing to those obtained by the simple GAs.

- Important advantage of the SPEA2 is that it is faster and requires less memory resources.

12 Future Work

- Application of the technique to the larger and more detailed safety system.

- Testing the effectiveness of the technique on the system with dependencies.

Thank You Very Much!