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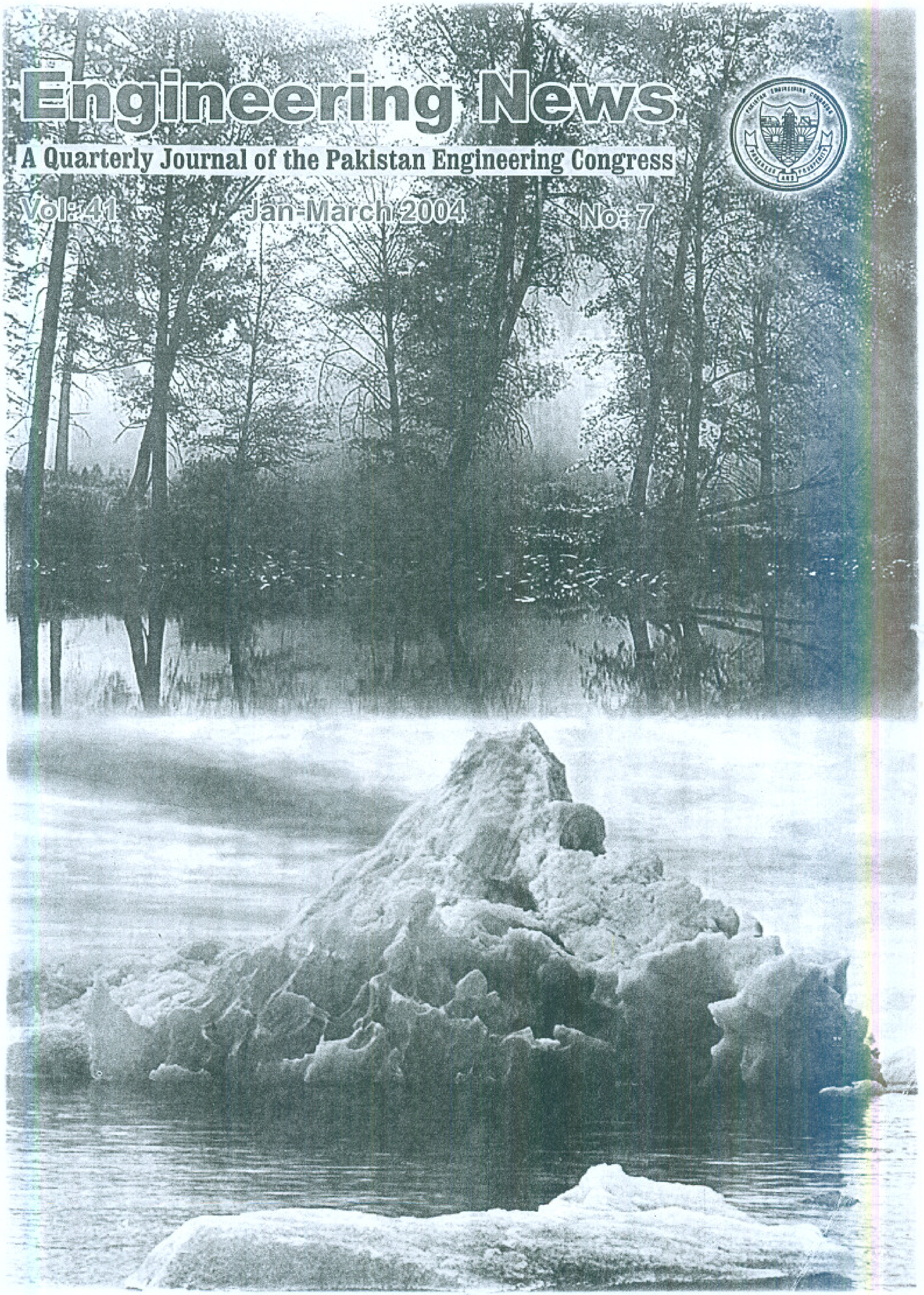

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46th YEAR OF PUBLICATION

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EDITORIAL

COMPUTER SIMULATION FOR IMPROVEMENT OF SYSTEMS

This issue of the Engineering News Journal enlightens the growing role of computer simulation in making the management effective and efficient and to gain financial benefits by exposing the non-value adding activities and risks to failures. "Simulation" can be extremely general term since the idea applies across many fields, industries, and applications. Simulation refers to a broad collection of methods and applications to mimic the behaviour of real systems, usually on a computer with appropriate software.

Simulation is becoming a standard decision-making tool in the engineering projects. The simulator designers are trying to cover almost every aspect of the project. Simulation packages are available that allow simulation for the ergonomics of man/machine interface, robot movements for workplace planning and control programming, modelling economy and their various (and conflicting) predictions, and logistics and supply chain management.

Simulation is being considered to solve a particular problem, but the trend is changing, because simulation allows to play with the system and to check system performance in different scenarios. In other words, it answers the "What If" questions and indicates the system risk to failure. Now it is tried to employ in the early stages of the project, especially in the design phase to have it's greatest impact.

This technology is still new to Pakistan, but it is getting its grip. Institutes are realizing its importance because competition among the manufacturers is increasing on daily basis and margin to profit is decreasing simultaneously.

NEWS

IRRIGATION DEPT INKS DEAL FOR BARRAGES FEASIBILITY STUDY

Lahore (PR). The Punjab Irrigation and Power Department has signed an agreement with a consortium of three firms of Consulting Engineers led by M/s. National Development Consultants (NDC) for preparing 'Feasibility Study for Punjab Barrages Rehabilitation Project Phase I'. The project includes the design work for a completely new barrage at Khanki to replace the old weir and the rehabilitation and remodeling of Suleimanki and Taunsa Barrages.

The two other Partners of the Consortium are M/s. NESPAK and M/s Atkins of U.K.

The agreement was signed by Ihsanullah Sardar, Chief Engineer of Irrigation and Power Department and Ch. Ghulam Hussain, Managing Partner of M/s. National Development Consultants. Among others, Javaid Majid, Secretary Irrigation, Punjab was also present at the ceremony.

The feasibility studies will be completed within a period of one year from the date of commencement.

Khanki Headworks is actually over a hundred years old weir which, due to aging wear and tear, will now be replaced by constructing a new barrage on River Chenab. The Lower Chenab Canal takes off from Khanki and irrigates vast tracts of land in the Districts of Gujranwala, Sheikhupura, Faisalabad, Toba Tek Singh and Jhang. The canals off taking from Taunsa and Suleimanki Barrages irrigate lakes of acres of land in the Districts of D.G. Khan Muzaffargarh, Pakpattan, Bahawalnagar, Okara and Vehari.

The engineering services to be provided by the joint venture include: (a) preparation of feasibility studies, Plan for each barrage for design and construction phases on priority basis ; (b) feasibility and cost estimates ; (c) PC-I Proforma and (d) suggest the phased implementation schedule according to priority.

On completion of the project, performance of these barrages will considerably improve resulting in better flow and efficient increase in the supplies of irrigation water through the canals off taking from these barrages.

Mr. Ihsanullah Sardar, Chief Engineer Irrigation and Power Development and
Ch. Ghulam Hussain, Managing Partner NDC are seen exchanging documents after singing an agreement of Rehabilitation and Remodelling of Barrages in the Punjab Province. Secretary I & P, Mr. Javed Majid was also present at the occasion.

The Sindh Irrigation and Power Department has signed an agreement with a consortium of three firms of Consulting Engineers led by National Development Consultants (NDC) for providing engineering services and construction supervision of a vast networks of irrigation and drainage system in Sindh which needs revamping and rehabilitation.

The Project will cost Rs. 12 billion and will-be completed in four years. The two other firms of the Consortium are Engineering Consultants International Private Limited (ECIL) and Engineering Associates (EA) of Karachi.

The agreement was signed by Mr. Bashir Ahmed Dahar, Secretary, Irrigation and Power Department, Government of Sindh and Ch. Ghulam Hussain, Managing Partner of NDC, Mr. Akhlaq Ahmad of ECIL and Mr. Muzmmal Qureshi of Engineering Associates.

On return from Karachi after singing the agreement, Engr. Ch. Ghulam Hussain today gave details of the gigantic irrigation project. He said that the vast irrigation system of Sindh comprises 7 canals off-taking from Sukkur Barrage, 4 canals off-taking from Kotri Barrage and 3 canals off-taking from Guddu Barrage. Total length of these canals is 18,500 kilometers with related infrastructure of barrages, water falls, regulators and cross regulators, super-passages, siphons and aqueducts etc. he said the infrastructure of the irrigation system in Sindh had deteriorated over the years from frequent breaches at canal banks and clogging of irrigation channels with sediments and debris.

He said that the Consultants responsibilities include planning, design, procurement, implementation and detailed construction supervision of the Project. Other engineering services to be provided include repair and replacement of regulators and gates ; replacement of road bridges ; repair of modules ; revamping of telecommunication system on canal networks, rehabilitation and replacement of tube-wells and pumping stations ; repair of water courses ; bed clearance and strengthening of banks of the drains.

On completion of the Project after 4 years, the irrigation and drainage system after revamping and rehabilitation will be operating for another 100 years to achieve their envisaged objectives. Wastage of water will substantially be reduced ; more land will be reclaimed from water logging, new areas will come under irrigation, yield of crops will increase, socio-economic conditions of farmers will improve with relative increase in GDP besides opening new opportunities of employment, he said.

Ch. Ghulam Hussain said that a team of very experienced engineers led by Mohammad Idris Rajput, a former Secretary Irrigation and Power Department, Sindh has been approved by the Government of Sindh to carry out this gigantic assignment.

Secretary, Irrigation and Power Department, Government of Sindh, Bashir Ahmed Dahar and Consultant's Representative Ch. Ghulam Hussain of NDC, Akhlaq Ahmed of ECIL and Muzammal Qureshi of EA are signing the agreement.

WHAT IS THE WORLD'S OLDEST MAP?

Cartography's early past is lost in the depths of time. Obviously, the first maps were drawn in the sand or mud, used by one hunter to show another where the best hunting was, perhaps. Next maps must have been drawn on materials-bone, wood, or animals skins that have not survived. Among the first map materials to have survived intact are clay tables. A Babylonian clay tablet that has been widely accepted as "the earliest known map" was dug up in 1930 in the ruined city of Ga-Sur at Nuzi, near the towns of Harran and Krikuk, 200 miles north of the site of Babylon in the present-day Iraq.

Measuring only 7.6 x 6.8 cm, and in rather poor shape, the map most likely dates from the dynasty of Sargon of Akkad (2300-2500 B. C.) The tablet is etched with a map showing two ranges of hills on either of a stream. Cuneiform characters and stylized symbols identify some features and places. Like a modern cadastral map, the tablet depicts a 12-hectare plot owned by an individual called Azala. Only one place name on the map connects it to today's landscape, that of Mashkan-dur-ibla, placing it near the modern region of Yorgan tepe. The compass directions are shown with inscribed circles, and the tablet uses the sexagesmile system of mathematical cartography developed by the Babylonians. Of course there are many other contenders for the title of the world's oldest map, but this one is truly the great-granddaddy of today's topographic map.

(Contributed by A. W. Mir)

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BLUETOOTH (NEW WIRELESS TECHNOLOGY)

What is Bluetooth?

Blue tooth wireless technology is an international specification for a compact, low-cost radio solution that links portable devices – such as PC's, mobiles phones and handheld devices – with each other.

How Does Bluetooth Work?

Bluetooth devices are miniature, short-range radio transceivers that work in the international industrial, scientific, and medical devices (ISM) band of 2.45 GHz. Their typical working range is up to about 10m (33ft).

When any, tow Bluetooth devices come range, they automatically detect each other and establish a "conversation" to find out whether or not they are supposed to communicate. If they are, they then establish what is referred to as a "Pico net" or personal area network (PAN). This process only takes a few seconds, and afterwards data transfer can occur. As a result, Bluetooth technology is very easy to use; after the first configuration, Bluetooth connections are automatic.

Can Bluetooth Devices Interfere with each Other?

One of the major design goals of the Bluetooth standard has been to ensure that Bluetooth devices can work alongside other, whether or not they are intended to communicate.

The technical solution to this problem is the use of a radio technology known as spread spectrum. Spread spectrum technology allows radio devices to share a frequency without interfering, even if they are within range of each other. The type of spread spectrum used in Bluetooth is called frequency hopping, the two devices establish a connection and then "hop" around a large portion of the radio spectrum, using a pattern which looks random but which in fact is known precisely by both the transmitter and the receiver. Bluetooth devices that have established their Piconet hop through 79 different frequencies at a rate of 1, 600 frequency changes every second.

Because the hopping pattern for each Pico net is different, Bluetooth devices in different Pico nets can be using the same frequency range and be within range of each other, but still not interfere. Another advantage of spread spectrum technology is that it makes Bluetooth system very resistant to "jamming" from non-Bluetooth devices such as cordless telephones on the same ISM band.

How Secure is Bluetooth?

The data stream between Bluetooth devices is securely encrypted. Furthermore, frequency hopping makes it almost impossible to "eavesdrop".

(Contributed by A. W. Mir)

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WELCOME TO NEW MEMBERS

The Executive Council of the Pakistan Engineering Congress approved Membership of the following new members into the Congress fold. The Engineering News congratulates all of them and welcomes to PEC Fold.

Members admitted on 31-12-2003

1. Engr. Ahmad Rizwan
2. Engr. Syed Asim Vaseem
3. Engr. Rehan Gulzar
4. Engr. Fahim ud Din

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WATER ALLOWANCE OF MAJOR CANALS OF UPPER INDUS BASIN IRRIGATION SYSTEM: THE CURRENT STATUS

By

Ch. Karamat Ali, M. Azhar Javaid and Dr. M. Javed*

ABSTRACT

Today the volume of water supply does not match with the time pattern of crop needs. The cropping intensity (C.I) of the Punjab Irrigation System (PIS) making upper part of the Indus Basin now almost has doubled. To assess the crop water needs for in practice intensity on scientific basis, the DLR initiated this exercise with recent 5 years crop data (1998-2002). The reference evapotranspiration (ET_o) through CROPWAT Model and crop coefficient values worked out by IWMI were used as reference for the best assessment of crop water requirements, however, the data on rainfall (1993-2002) and cropping pattern was updated. The metdata values for rainfall were extrapolated through geographic information system (GIS) for different canal commands. The study reveals that C.I of Punjab Irrigation System has shifted to 128% against that of the system designed at 65 percent. This works out the annual crop water requirement of 73.75 MAF at canals heads against the 55.94 MAF as per Water. Apportionment Accord 1991. Under the current cropping pattern with 128% C.I, the water allowance needs adjustment at 4.9 against the currently followed 4.1 cusecs/1000 acres in Punjab. Shifting of C.I from 128% to the potential intensity of 147% (the highest value in the data), would require a water allowance of 7.36 cusecs. This works out a total water requirement of 110 MAF against 73.75 MAF assessed at the existing cropping pattern with 128% cropping intensity, 48.7% canal losses and 51.3% canal system efficiency. This stresses the need for constructing more reservoirs to manage the erratic flow pattern of our rivers and also to train the pattern of annual surplus water availability in the Indus Basin Irrigation System.

INTRODUCTION

Apart from operation and management of the present irrigation system, the cropping intensity and change in weather elements have put very high pressure on water demand. During the last fifty years, water demand for irrigation has substantially increased due to increasing cropping intensities. This left no choice, but to determine irrigation water requirements for scientific development of agriculture in the canal command (WAPDA, 1979).

Presently, rapid exploitation of groundwater in Upper Indus Basin irrigation system comprising of Punjab has met to some extent the requirement of increasing cropping intensities. The recovery of this by-product of surface water at high cost is also yielding to soil salinity and sodicity problems (Javaid and Yamin, 2003 a). The oil and electricity prices soaring very high will no more permit the groundwater abstraction by the poor farmers to match the volume of water supply with the time pattern of crop needs. The canal seepage losses are picked up by Punjab farmers at a very high cost of Rs. 1000 to 1200 per acre foot, while even good groundwater has 3-4 times the dissolved salts compared to river water (Ali, 2001). A part from un-favourable sodium to calcium ratios facilitating sodium adsorption on soil colloids, the high carbonate ions in groundwater is aggravating to soil sodicity (Javaid and Yamin, 2002, Javaid, 1998). This highlights the need of effective canal water management and its distribution to canal commands to minimize the mismatch of water supplies to crop water requirement (Javaid and Yamin, 2003 b). There are a number of options available with the Irrigation Managers and Policy Makers to argument water supply. These range from judicious water resource use to broadening of the water resource base.

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In view of water demand, it is the high time to keep an eye on pattern of surplus water availability, river supplies, future irrigation schemes and future reservoirs. How much we have to produce to overcome demographic pressure, what are our real needs, how many reservoirs and of what capacity we have to plan and implement-all such policy decisions depend on assessment of the crop water needs. The remodeling of our irrigation system designed at 65% cropping intensity also depends on our crop water needs. Now the cropping intensity in some of the canal commands almost has doubled, still in other canals it has touched to the figure of 198%. The water allowance of our canals needs re-assessment because of current cropping practice. The assessment of crop water needs is not only required for better distribution of canal supplies, but also to synchronize demand – supply gap at the command area level for sustainable management of water resources (Kaleemullah *et al.*, 2001). In view of aforementioned situation the in hand exercise was undertaken with an eye on the following objectives:

- Assessment of crop water requirement based water allowance of the Punjab Irrigation Network.
- Determination of the current annual cropping intensity of the system
- Determination of current and potential total crop water requirement

DATA AND INFORMATION SOURCE

The crop data for intensity and cropping pattern was collected from the Punjab Irrigation Department. The cropped area during Kharif 1998 to Rabi 2002-2003 was averaged to work out average annual cropping intensity for different canal commands (Table 1). The reference evapotranspiration (Table 2) and crop co-efficients (Table 3) worked out by Kaleemullah (2001) for different crops were used and for best estimate, the canals were grouped (foot note of table 3). The data (originally used for ET_o) on mean monthly values for maximum and minimum temperature, wind speed, humidity and daily sunshine hours (one year) for long period (20-25 years) was collected by IWMI from Pak. Meteorological Department (PMD) . The Directorate of Land Reclamation updated the crop (1998-2003) and rainfall data for the years, 1993-2002 (Table 4) to assess the current crop water needs. The rainfall data was extrapolated through GIS input by contouring / polygon technique for different canal commands as PMD provided Metdata of only 11 Met. Stations, available in Punjab.

The reference ET_o values through CROPWAT Model for different canal commands were worked out by IWMI. These values were used to assess crop water requirement and adjust water allowance of 24 major canals of Punjab Irrigation System. The CROPWAT Model based on penman – Monteith equation has originally been used for reference ET_o. The basic equation involved is as follows:

$$ET_o = [0.408 \quad (R_n-G) + r x\, 900/T+273xU2\, (e_s-e_a)] / [\quad + r\, (1+0.34\, U_2)]$$

Where:

ETo	=	reference evapotranspiration (mm / day)
R_n	=	net radiation at the crop surface (MJ / m^2 day)
G	=	soil heat flux density (MJ / m^2 day)
T	=	mean daily temperature at 2 m height
U_2	=	wind speed at 2 m height (m/sec)
e_s	=	saturation vapour pressure (Kpa)
e_a	=	actual vapour pressure (Kpa)
e_s-e_a	=	saturation vapour pressure deficit (Kpa)
	=	slope vapour pressure curve (Kpa/^oC)
r	=	psychrometric constant (Kpa/^oC)

Fig.1 Best estimated relationship between precipitation and effective precipitation

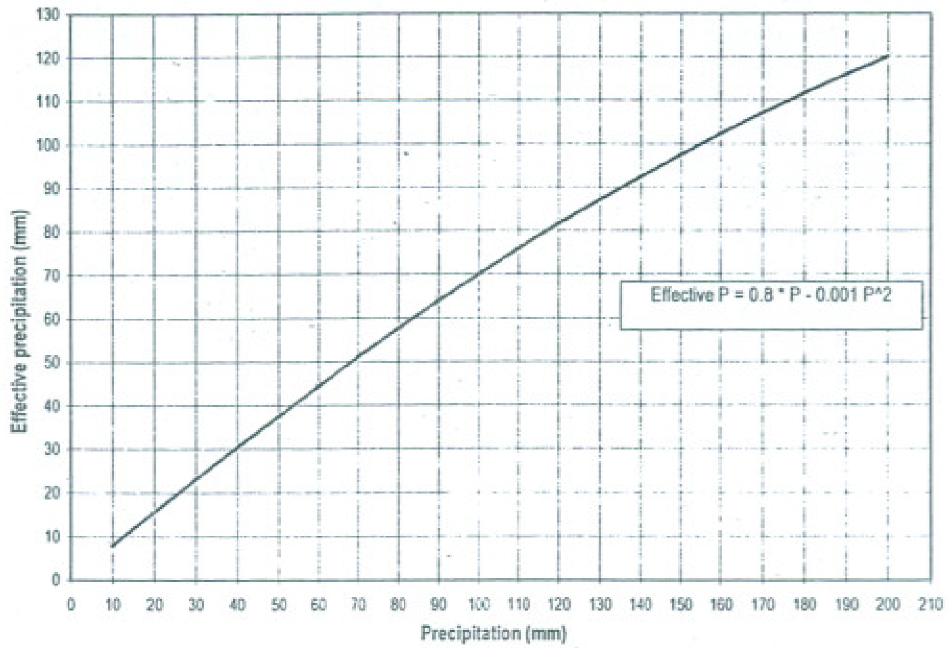


FIG. 2 CROP WATER REQUIREMENTS OF PUNJAB CANALS AT CANAL HEAD (MAF)

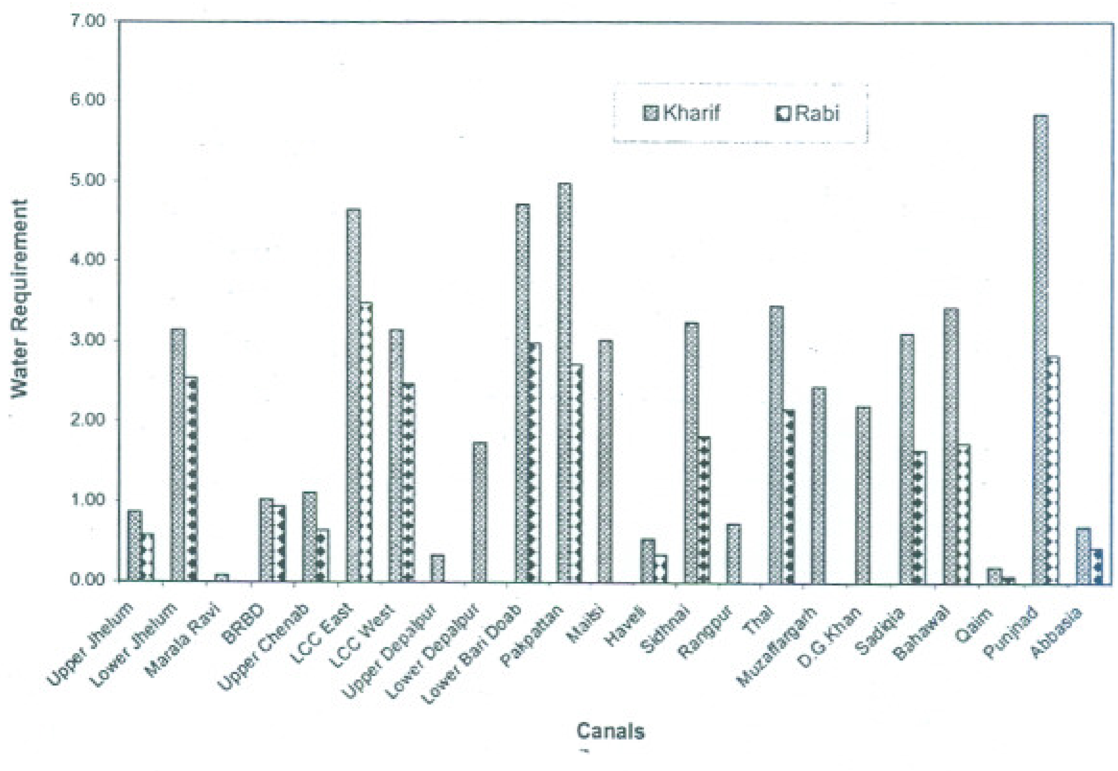


TABLE I. **Average Cropped Area during Kharif 1998 to Rabi 2002-03 in Canal Commands of Punjab Irrigation Network**

#	Crops\canal	UJC	LJC	MRL	BRB	UCC	LCCE	LCCW	UDC	LDC	LBDC	PKN	MLS	HVL	SDN
	CCA	603,749	1,518,401	155,348	611,588	816,927	2,205,809	1,209,136	361,934	614,087	1,670,545	1,296,100	702,496	151,935	947,694
	Cropping intensity %	101.25	128.46	48.34	151.02	99.52	118.42	151.72	53.24	101.99	154.72	167.46	171.22	160.46	142.96
	Weighted Crop Int %	2.95	9.43	0.36	4.46	3.93	12.62	8.87	0.93	3.03	12.49	10.49	5.81	1.18	6.55
	Kharif,crops														
1	Cotton	5,036	24,351		28,749	169	109,669	56,783	2,693	32,564	477,992	572,164	499,992	29,748	351,143
2	Maize	11,484	99,185	48	38,049	17,173	215,460	225,612	14,445	98,253	246,195	117,124	6,193	4,337	31,988
3	Rice	126,127	75,924	36,406	155,844	349,767	280,609	73,274	50,037	118,772	141,113	106,771	9,585	24,203	42,156
4	K.oilseeds	1,868	2,630	15	3,799	3,402		35,932	4,136	15,007	7,921	17,870			1,065
5	K.pulses				12,952	10,013									1,323
6	K.fodder		108,076	795	142,982	64,049	188,286	33,473	32,340	76,976	41,479		35,583	26,926	105,649
7	K.veges	17,068		45	24,841	27,126			3,830						
8	Sorghum	134,634	223,662	859			45,357	116,716	3,011	51,960	204,767		48,773		
9	K.misc.other		45,123	187	4,169		141,499	72,394	6,178	84,979	41,479	238,398	45,975	10,530	54,123
	Kharif total	296,217	578,951	38,355	411,385	471,699	980,880	614,184	116,670	478,511	1,160,946	1,052,327	646,101	95,744	587,447
	Rabi crops														
10	Wheat	150,926	528,213	19,970	244,342	193,738	805,283	560,398	25,896	43,444	831,357	811,556	475,132	78,325	424,487
11	Barley		4,623						4,116	846	10,094		3,710		
12	Gram		1,624	43			2,000	2,311		140	1,867	2,120	629		
13	R.oilseeds	2,059	7,383	271	6,686	4,697	86,589	84,877	443	535	131,424	69,747	7,154	999	11,777
14	R.pulses			52	13,607	3,249			123						
15	R.fodder	68,683	182,011	9,022	115,360	80,815	182,383	94,485	6,462	487	37,525			23,955	105,364
16	R.veges	15,245		354	16,675	13,150			1,587						
17	R.misc.other		41,199	6,768	26,716	24,357	64,636	36,408	226	50,382	182,979	80,361	27,158	2,846	9,929
	Rabi Total	236,913	765,053	36,480	423,386	320,006	1,140,891	778,479	38,853	95,834	1,195,246	963,784	513,783	106,125	551,557
	Annual crops														
18	Sugarcane	36,716	145,607	104	36,433	9,688	224,250	205,164	18,183	24,366	93,324	50,423	6,747	14,156	11,410
19	Garden	781	157,650	22	5,958	970	20,870	15,769	290	1,620	20,918	26,725	14,714	6,806	96,483
20	Forest	1,589		7	2,048				110						
	Annual Total	39,086	303,257	133	44,439	10,658	245,120	220,933	18,583	25,986	114,242	77,148	21,461	20,962	107,893
	Annual croping intensity %	101.3	128.5	48.3	151.0	99.5	118.4	151.7	53.2	102.0	154.7	167.5	171.2	160.5	143.0

Continued..

	Crops\canal	RGR	THL	MGR	DGK	FDW	SDQ	BWL	QAM	PND	ABS	TOTAL
	CCA	231,932	1,912,166	807,000	934,000	430,092	1,073,391	754,293	41,571	1,388,500	250,699	20,689,393
	Cropping intensity %	136.67	108.76	126.07	92.12	120.06	122.30	176.06	169.80	149.44	120.28	128.01
	Weighted Crop Int %	1.53	10.05	4.92	4.16	2.50	6.34	6.42	0.34	10.03	1.46	130.86
	Kharif crops											
1	Cotton	57,890	131,626	202,997	358,036	58,961	399,425	392,968	24,018	661,551	74,230	4,552,755
2	Maize	3,225	5,031	10,861	5,685	11,038	20,171	5,191	813	12,579	16,191	1,216,331
3	Rice	31,790	32,902	43,209	50,348	70,159	26,112	10,007	4,225	43,318	2,130	1,904,788
4	K.oilseeds		31,035		183	9,096	10,925	9,837	1,079	1,371	167	157,338
5	K.pulses											24,288
6	K.fodder	41,161	111,059	77,867		6,450	21,984	50,787	2,418	67,121	18,415	1,253,876
7	K.veges			30,775	1,193							104,878
8	Sorghum		314,774			97,672	115,729	50,240	1,333	42,925	8,459	1,460,871
9	K.misc.other	14,044	242,215	98,827	14,649			116,381	1,283	81,415	337	1,314,185
	Kharif total	148,110	868,642	464,536	430,094	253,376	594,346	635,411	35,169	910,280	119,929	11,989,310
	Rabi crops											
10	Wheat	104,351	666,737	313,994	336,100	156,212	432,872	422,845	23,497	639,004	86,596	8,375,275
11	Barley		53,498	571		18,685	25,114	162	45		397	121,861
12	Gram		71,455		12,745			1,080	52	286		96,352
13	R.oilseeds	213	61,869		7,957	3,394	99,868	38,100	944	25,478	3,596	656,060
14	R.pulses											17,031
15	R.fodder	35,358	48,777	73,676	37,284	49,528	38,106	61,607	3,960	85,086	18,834	1,358,768
16	R.veges			32,439	921							80,371
17	R.misc.other	1,415	78,678	35,812	10,559	5,787	6,640	74,139	328	57,194	31,675	856,192
	Rabi Total	141,337	981,014	456,492	405,566	233,606	602,600	597,933	28,826	807,048	141,098	11,561,910
	Annual crops											
18	Sugarcane	9,107	85,047	47,012	9,616	11,334	39,094	24,268	1,353	69,582	6,379	1,179,363
19	Garden	4,659	29,982	1,158	2,750	3,351	18,791	21,533	1,881	109,271	3,287	566,239
20	Forest							1,546	63		10,593	15,956
	Annual Total	13,766	115,029	48,170	12,366	14,685	57,885	47,347	3,297	178,853	20,259	1,761,558
	Ann. Crop Int. %	136.7	108.8	126.1	92.1	120.1	122.3	176.1	169.8	149.4	120.3	130.9

It is notable that even on non-perennial canals the cropped area has been recorded. This may be due to the installation of tubewells or it may be simply rain fed, not canal irrigated.Sometimes data values on cropping intensities are rounded, which account to a any slight difference noted in the tabulated data

UJC = Upper Jehlum canal, LJC = Lower Jehlum canal, MRL = Marala-Ravi Link, BRB = Bombanwala Ravi Bedian, UCC = Upper Chenab Canal, LCC E = Lower Chenab Canal East, LCC W = Lower Chenab Canal West, UDC = Upper Depalpur Canal, LDC = Lower Depalpur Canal, LBDC = Lower Bari Doab Canal, PKN = Pakpattan, MLS = Mailsi, HVL = Haveli Canal, SDN = Sidhani, RGPR = Rangpur, THL = Thal Canal, MGR = Muzaffargarh Canal, DGK = Dera Ghazi Khan, FRDW = Fordwah, SDQ = Sadiqia, BHWL = Bahawal, PJND =Punjnad, ABSA= Abbasia.

TABLE 2. Reference ET of different Canals ET_o (mm per month)

No.	Canal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Upper Jhelum	48	65	114	155	204	207	168	144	144	121	78	53	1,501
2	Lower Jhelum	48	67	117	158	211	216	179	156	147	118	74	51	1,542
3	Marala Ravi	39	58	104	141	182	184	149	140	125	92	51	36	1,301
4	BRBD	41	59	107	145	186	188	153	142	129	95	53	37	1,335
5	Upper Chenab	41	59	106	142	185	187	155	144	130	96	54	38	1,337
6	LCC East	43	62	111	147	193	195	165	150	138	101	56	41	1,402
7	LCC West	44	63	113	150	199	203	172	156	141	103	58	42	1,444
8	Upper Depalpur	43	62	112	151	195	195	162	146	136	100	55	40	1,397
9	Lower Depalpur	45	66	119	154	197	211	177	164	145	103	57	43	1,481
10	Lower Bari Doab	45	66	120	154	197	214	181	168	147	104	58	43	1,497
11	Pakpattan	47	69	126	157	198	227	193	182	155	107	59	46	1,566
12	Mailsi	47	69	126	157	198	227	193	182	155	107	59	46	1,566
13	Haveli	49	69	124	161	211	231	197	181	153	109	62	47	1,594
14	Sidhnai	47	69	126	157	198	227	193	182	155	107	59	46	1,566
15	Rangpur	49	69	124	161	211	231	197	181	153	109	62	47	1,594
16	Thal	48	67	120	157	207	222	190	173	150	108	61	46	1,549
17	Muzaffargarh	47	69	126	157	198	227	193	182	155	107	59	46	1,566
18	DG Khan	47	69	126	157	198	227	193	182	155	107	59	46	1,566
19	Fordwah	62	83	139	194	258	269	205	195	170	136	84	58	1,853
20	Sadiqia	59	81	132	180	235	250	199	190	164	129	79	55	1,753
21	Bahawal	56	78	126	165	211	230	193	185	159	122	74	52	1,651
22	Qaim	58	81	120	178	232	246	198	188	158	127	75	54	1,715
23	Punjnad	58	82	133	172	217	235	199	188	158	123	75	55	1,695
24	Abbasia	58	82	133	172	217	235	199	188	158	123	75	55	1,695
	Average	49	70	123	161	207	224	187	175	151	111	63	47	1,568

Source: IWMI Publication: Spatial distribution of reference and potential evapotranspiration (Working paper 24)

TABLE 3. Adopted crop co-efficients for different crops during different months for different canal groups*

Crop/zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cotton												
G2	-	-	-	-	0.33	0.72	1.11	0.98	0.68	0.45	0.25	-
G3	-	-	-	-	0.41	0.92	1.11	0.86	0.6	0.42	0.19	-
G4	-	-	-	-	0.25	0.72	1.11	0.98	0.66	0.47	0.26	0.25
G5	-	-	-	-	0.24	0.72	1.11	0.98	0.66	0.47	0.26	-
G6	-	-	-	-	0.41	0.91	1.11	0.86	0.58	0.43	0.2	-
G7	-	-	-	-	0.41	0.91	1.11	0.86	0.58	0.43	0.24	-
Maize												
G2	-	-	-	-	-	0.2	0.25	0.73	0.82	0.54	-	-
G3	-	-	-	-	-	0.2	0.22	0.73	0.82	0.54	-	-
G4	-	-	-	-	-	0.2	0.22	0.73	0.82	0.54	0.25	-
G5	-	-	-	-	-	0.2	0.2	0.57	0.82	0.7	0.2	-
G6	-	-	-	-	-		0.15	0.57	0.82	0.7	0.2	-
G7	-	-	-	-	-	0.25	0.51	0.9	0.91	0.43	-	-
Rice												
G2	-	-	-	-	0.75	1	1	1.38	1.15	0.55	0.2	-
G3	-	-	-	-	0.75	1	0.73	1.35	1.3	0.73	0.3	-
G4	-	-	-	-	0.75	1	0.73	1.35	1.29	0.73	0.3	-
G5	-	-	-	-	0.75	1	1.15	1.39	0.93	0.42	0.2	-
G6	-	-	-	-	0.75	1	1.15	1.39	0.93	0.42	0.2	-
G7	-	-	-	-	0.75	1	1.3	1.31	0.73	0.3	-	-
K. oilseeds												
All	-	-	-	-	0.4	0.8	1.05	0.85	0.6	-	-	-
K. Pulses												
All	-	-	-	-	0.4	0.4	0.8	1.15	0.6	0.2	-	-
K. Fodder												
All	-	-	-	-	0.3	0.3	0.5	0.65	0.96	0.81	0.2	-
K. Vegetables												
All	-	-	-	-	-	0.7	0.95	1.05	0.9	0.75	0.5	-
Sorghum												
G2	-	-	-	-	-	0.2	0.4	0.8	0.96	0.63	0.1	-
G3	-	-	-	-	-	0.2	0.3	0.65	0.96	0.81	0.2	-
G4	-	-	-	-	0.2	0.2	0.3	0.65	0.96	0.81	0.2	-
G5	-	-	-	-	0.2	0.2	0.3	0.65	0.96	0.81	0.2	-
G6	-	-	-	-	-	0.2	0.39	0.8	0.96	0.63	0.2	-
G7	-	-	-	-	-	0.24	0.51	0.9	0.91	0.43	0.2	-
K.Misc.												
G2	-	-	-	0.12	0.55	0.74	0.92	0.95	0.86	0.61	-	-
G3	-	-	-	0.12	0.55	0.74	0.92	0.95	0.86	0.61	-	-
G4	-	-	-	0.12	0.55	0.74	0.92	0.95	0.86	0.61	-	-
G5	-	-	-	0.48	0.68	0.83	0.84	0.84	0.72	0.15	-	-
G6	-	-	-	0.48	0.68	0.83	0.84	0.84	0.72	0.26	-	-
G7	-	-	-	0.48	0.68	0.83	0.84	0.84	0.72	0.26	-	-

Continu

Crop/zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat												
G2	0.87	1.1	0.97	0.56	-	-	-	-	-	-	0.2	0.5
G3	1	1.1	0.87	0.41	-	-	-	-	-	-	0.22	0.57
G4	1.02	1.15	0.88	0.43	-	-	-	-	-	-	0.22	0.57
G5	1.02	1.15	0.88	0.43	-	-	-	-	-	-	0.22	0.57
G6	1	1.1	0.72	0.25	-	-	-	-	-	-	0.32	0.6
G7	1	1.1	0.72	0.26	-	-	-	-	-	-	0.32	0.6
Barley												
All	Same as for wheat	-	-	-	-	-	-	-	-	-	-	-
Gram												
All	0.8	0.8	0.5	0.3	-	-	-	-	-	0.1	0.3	0.5
R. oil seeds												
G2	0.99	0.82	0.44	0.21	-	-	-	-	-	0.28	0.5	0.8
G3	0.99	0.82	0.44	0.21	-	-	-	-	-	0.28	0.5	0.8
G4	0.99	0.82	0.44	0.21	-	-	-	-	-	0.28	0.5	0.8
G5	0.99	0.82	0.44	0.21	-	-	-	-	0.2	0.28	0.5	0.8
G6	0.99	0.82	0.44	0.21	-	-	-	-	-	0.28	0.5	0.8
G7	0.96	0.7	0.35	0.15	-	-	-	-	0.1	0.34	0.6	0.9
R. Pulses												
All	0.9	0.85	0.36	0.21	-	-	-	-	-	-	0.26	0.51
R. Fodder												
All	1	1.1	1.1	0.9	0.7	-	-	-	0.4	0.6	0.8	1
R. vegetables												
All	1.05	1.05	0.95	0.9	-	-	-	-	-	0.4	0.8	0.95
R.Misc												
G2	0.98	0.89	0.75	0.49	-	-	-	-	0.1	0.36	0.7	0.88
G3	0.98	0.89	0.75	0.49	-	-	-	-	0.1	0.36	0.7	0.88
G4	0.95	0.86	0.66	0.2	-	-	-	-	0.1	0.36	0.7	0.88
G5	0.98	0.89	0.75	0.49	-	-	-	-	0.1	0.36	0.7	0.88
G6	0.98	0.89	0.75	0.49	-	-	-	-	0.15	0.46	0.79	0.93
G7	0.96	0.85	0.69	0.28	-	-	-	-	0.15	0.46	0.79	0.93
Sugarcane												
G2	0.68	0.4	0.46	0.71	0.97	1.19	1.19	1.19	1.19	1.19	1.19	0.96
G3	0.55	0.37	0.61	1.01	1.14	1.2	1.2	1.2	1.2	1.2	1.11	0.77
G4	0.3	0.37	0.61	1.01	1.14	1.18	1.25	1.17	1.08	1.02	0.85	0.47
G5	0.4	0.37	0.61	1.01	1.14	1.18	1.25	1.17	1.07	1.02	0.85	0.47
G6	0.4	0.46	0.71	0.97	1.13	1.15	1.15	1.15	1.15	1.13	0.96	0.68
G7	0.68	0.45	0.51	0.74	0.98	1.15	1.15	1.15	1.15	1.15	0.96	0.68
Garden												
All	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Forest												
All	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

G2= BRBD, UCC, MRL, Central Bari Doab (CBDC), Upper Depalpur Canal
G3= UJC, LJC, LCC(E), LCC (W).
G4= Lower Bari Doab Canal,and Lower Depalpur Canal.
G5= Mailsi, Sidhnai, Haveli, Pakpattan.
G6= Rangpur, Thal, Muzzaffargarh,D.G.Khan.
G7= Fordwah, Sadiqia, Bahawal, Qaim, Punjnad, Abbasia.

TABLE 4. Historic Average Rainfall (mm) for Period 1993-2002

Climatic station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Islamabad	-	53.4	71.8	74.2	56.3	26.7	76.8	348.7	370.6	103.3	34.8	13.0	24.6	1254
Jhelum	-	39.9	42.9	41.9	40.6	17.5	70.0	266.6	254.7	70.7	33.7	9.9	14.5	903
Sialkot	-	43.7	46.2	38.9	32.0	18.0	81.3	307.2	317.1	83.9	32.4	9.2	7.9	1018
Lahore	-	19.7	23.2	21.5	17.4	17.1	67.9	204.4	201.0	56.6	17.1	11.2	5.7	663
Faisalabad	-	8.4	9.0	9.7	25.8	8.8	70.2	81.6	61.6	54.4	7.9	2.6	3.1	343
Sargodha	-	19.6	23.2	20.4	40.3	31.2	48.0	118.4	112.4	36.2	16.2	6.4	8.6	481
Mianwali	-	29.5	38.4	63.9	67.4	21.9	43.6	146.1	120.3	35.3	35.6	4.6	8.3	615
Multan	-	7.0	11.8	9.6	17.4	25.7	23.6	68.1	21.3	43.7	14.5	0.5	4.2	247
Bahawalnagar	-	14.9	11.0	16.2	9.1	42.3	49.2	97.1	32.6	11.6	20.9	1.2	1.3	307
Bahawalpur	-	6.1	8.4	6.4	8.5	13.3	20.0	46.3	30.5	15.4	14.7	1.3	1.2	172
Average	-	*24*	*29*	*30*	*31*	*22*	*55*	*168*	*152*	*51*	*23*	*6*	*8*	*600*
WEIGHTED RAINFALL (mm) FOR CANAL COMAND AREAS														
	CCA	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
UJC	603,749	36.3	39.4	37.8	40.2	20.1	66.4	240.8	230.9	64.8	30.4	9.2	13.1	829
LJC	1,518,401	19.6	23.2	20.4	40.3	31.2	48.0	118.4	112.4	36.2	16.2	6.4	8.6	481
MRL	155,348	43.7	46.2	38.9	32.0	18.0	81.3	307.2	317.1	83.9	32.4	9.2	7.9	1,018
BRB	611,588	25.9	29.2	26.0	21.2	17.3	71.4	231.1	231.2	63.7	21.1	10.7	6.3	755
UCC	816,927	30.5	33.6	29.3	24.0	17.5	73.9	250.7	253.2	68.9	24.0	10.3	6.7	823
LCCE	2,205,809	9.6	10.6	11.0	23.4	10.8	66.1	93.9	74.7	51.7	9.3	3.5	3.3	368
LCCW	1,209,136	8.4	9.0	9.7	25.8	8.8	70.2	81.6	61.6	54.4	7.9	2.6	3.1	343
UDC	361,934	19.7	23.2	21.5	17.4	17.1	67.9	204.4	201.0	56.6	17.1	11.2	5.7	663
LDC	614,087	19.4	22.5	21.2	16.9	18.6	66.8	198.0	190.9	53.9	17.3	10.6	5.4	641
LBDC	1,670,545	11.3	10.7	12.9	15.4	29.8	48.1	86.0	37.0	30.3	16.1	1.4	2.5	301
PKN	1,296,100	11.8	11.3	13.6	12.3	35.8	39.2	85.8	28.2	24.1	18.4	0.9	2.4	284
MLS	702,496	6.8	9.7	7.9	11.5	18.8	22.6	56.0	27.6	24.5	14.9	1.0	2.2	204
HVL	151,935	7.3	11.3	9.6	19.0	22.6	32.2	70.6	28.8	45.7	13.3	0.9	4.0	265
SDN	947,694	7.0	11.8	9.6	17.4	25.7	23.6	68.1	21.3	43.7	14.5	0.5	4.2	247
RGR	231,932	7.0	11.8	9.6	17.4	25.7	23.6	68.1	21.3	43.7	14.5	0.5	4.2	247
THL	1,912,166	17.6	23.9	32.7	40.4	24.9	34.8	105.8	72.7	39.4	23.2	2.9	6.4	425
MGR	807,000	6.7	10.8	8.6	14.7	22.0	22.5	61.6	24.1	35.2	14.6	0.7	3.3	225
DGK	934,000	6.5	9.8	7.7	12.1	18.3	21.4	55.0	26.8	26.7	14.6	1.0	2.4	202
FDW	430,092	14.9	11.0	16.2	9.1	42.3	49.2	97.1	32.6	11.6	20.9	1.2	1.3	307
SDQ	1,073,391	13.6	10.6	14.8	9.0	38.1	45.0	89.7	32.3	12.2	20.0	1.2	1.3	288
BWL	754,293	6.1	8.4	6.4	8.5	13.3	20.0	46.3	30.5	15.4	14.7	1.3	1.2	172
QAM	41,571	6.1	8.4	6.4	8.5	13.3	20.0	46.3	30.5	15.4	14.7	1.3	1.2	172
PND	1,388,500	6.1	8.4	6.4	8.5	13.3	20.0	46.3	30.5	15.4	14.7	1.3	1.2	172
ABS	250,699	6.1	8.4	6.4	8.5	13.3	20.0	46.3	30.5	15.4	14.7	1.3	1.2	172
TOTAL	20,689,393	14.5	16.8	16.0	18.9	21.5	43.9	114.8	89.5	38.9	17.5	3.8	4.1	400

Abbreviations for canals are same as used in Table-1.

FORMULAE USED

1. $ET_G = ET_o \times Kc$
2. $Net\ ET = ET_G - Pe$

Where: ET_G = gross evapotranspiration (mm)
ET_o = reference evapotranspiration (mm)
Kc = crop co-efficient
Pe = effective rainfall (mm)

3. ***Crop Water Requirement (MAF)*** = [Net ET (mm) x crop month area (acres)] / 304.8 x 10^6

4. ***Water Allowance (cusec/1000 acres)*** = [CWR (MAF) x 10^6 x 1000] / [365 x 1.98325 x CCA]

5. ***Effective Rainfall (Pe)*** $= 0.8\,P - 0.001\,P^2$
Where: P = precipitation (rainfall) in mm.

6. ***Cropping Intensity (C.I)*** = [cropped area/CCA] x 100

7. ***Potential Water Allowance (WA)*** was calculated as under:
WA = [(highest intensity in data years) x (WA at average intensity)] / [average intensity of data years]

The effective rainfall bases on the best estimate and Fig. 1 delineates the relationship developed. It is also cleared that value of crop co-efficient (Kc) varies with crop, the individual crop month (the month in which crop stands) and even the area location and more accurately with the crop growth stages. Help in this regard was sought from FAO paper to compute crop coefficient for different crops (FAO, 1998). It is also explained that while using formula No.3 to work out crop water requirement of each month the area under the crop during that month was used.

ASSUMPTIONS

Field losses = 25%, Water course losses =20%

Disty. losses = 10%, Main canal losses = 5%

Main canal + distribution losses = 5+10 = 15%

DISCUSSION

a. Present Cropping Intensity

A perusal on the data (Table 5) reveals that present cropping intensity based on average cropped area during 1998-2002 has increased to 176% in command area of Bahawal canal followed by Mailsi (171%) and Qaim canal (170%). Except at Marala Ravi Link, Upper Depalpur and D.G. Khan, the cropping intensity has gone above 100%. Thus on the average, the cropping intensity in Punjab has been worked out to be 128% against the 65% at which irrigation system has been designed.

TABLE 5. Crop Water Requirements of Punjab Canals at Canal Head (MAF)

Based on average cropped area during 1998-2002	Canal system efficiency % = 51.3	Canal losses % = 48.7

Canal	CCA acres	C.I %		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Water required MAF			Required WA			Exis WA	Potential Annl
		Pres	Pot													Kharif	Rabi	Annl.	Kharif	Rabi	Annl.		
Upper Jhelum	603,749	101	125	0.03	0.06	0.14	0.13	0.09	0.18	0.12	0.06	0.24	0.17	0.12	0.10	0.87	0.58	1.45	3.95	2.68	3.32	3.03	4.09
Lower Jhelum	1,518,401	128	139	0.20	0.31	0.62	0.57	0.52	0.66	0.41	0.30	0.69	0.57	0.45	0.40	3.14	2.54	5.69	5.71	4.64	5.18	2.84	5.60
Marala Ravi	155,348	48	81	-	-	-	-	0.01	0.02	0.02	0.01	0.02	0.01	-	-	0.08	-	0.08	1.48	-	1.48	3.79	2.48
BRBD	611,588	151	180	0.05	0.11	0.25	0.25	0.12	0.24	0.17	0.08	0.24	0.17	0.14	0.15	1.03	0.95	1.98	4.64	4.29	4.47	2.73	5.32
Upper Chenab	816,927	100	119	0.03	0.08	0.17	0.16	0.06	0.25	0.24	0.14	0.28	0.15	0.11	0.11	1.12	0.65	1.76	3.76	2.20	2.98	2.73	3.57
LCC East	2,205,809	118	130	0.32	0.46	0.81	0.75	0.67	0.90	0.73	0.69	0.88	0.78	0.58	0.56	4.65	3.48	8.13	5.81	4.37	5.09	2.84	5.59
LCC West	1,209,136	152	160	0.23	0.32	0.57	0.53	0.50	0.64	0.47	0.47	0.55	0.52	0.41	0.40	3.15	2.48	5.62	7.17	5.67	6.42	2.84	6.77
Upper Depalpur	361,934	53	61	-	-	-	-	0.04	0.08	0.06	0.03	0.08	0.05	-	-	0.34	-	0.34	2.59	-	2.59	5.50	2.97
Lower Depalpur	614,087	102	131	-	-	-	-	0.14	0.24	0.29	0.48	0.39	0.20	-	-	1.74	-	1.74	7.80	-	7.80	5.50	10.02
Lower Bari Doab	1,670,545	155	183	0.28	0.49	0.73	0.50	0.47	0.93	0.80	1.10	0.90	0.53	0.49	0.49	4.72	2.98	7.70	7.78	4.95	6.37	3.33	7.53
Pakpattan	1,296,100	167	185	0.25	0.43	0.64	0.58	0.63	1.23	1.00	1.10	0.72	0.30	0.40	0.44	4.98	2.72	7.70	10.59	5.82	8.21	3.60	9.07
Mailsi	702,496	171	184	-	-	-	-	0.34	0.79	0.66	0.64	0.40	0.19	-	-	3.02	-	3.02	11.84	-	11.8	5.50	12.72
Haveli	151,935	160	171	0.03	0.05	0.09	0.08	0.07	0.11	0.12	0.12	0.08	0.05	0.05	0.05	0.54	0.35	0.89	9.88	6.32	8.10	3.00	8.64
Sidhnai	947,694	143	154	0.18	0.28	0.47	0.38	0.41	0.79	0.66	0.69	0.42	0.28	0.26	0.26	3.24	1.83	5.07	9.43	5.34	7,39	3.00	7.96
Rangpur	231,932	137	143	-	-	-	-	0.09	0.17	0.16	0.16	0.10	0.07	-	-	0.74	0.00	0.74	8.82		8.82	4.80	9.23
Thal	1,912,166	109	131	0.22	0.34	0.45	0.35	0.55	0.80	0.53	0.60	0.65	0.32	0.40	0.40	3.45,	2.16	5.61	4.98	3.13	4.06	3.18	4.88
Muzaffargarh	807,000	126	129	-	-	-	-	0.33	0.62	0.50	0.48	0.32	0.21	-	-	2.45	-	2.45	8.35	-	8.35	6.36	8.54
DG Khan	934,000	92	112	-	-	-	-	0.27	0.65	0.51	0.42	0.23	0.12	-	-	2.20	-	2.20	6.49	-	6.49	6.36	7.89
Fordwah	430,092	120	167	-	-	-	-	0.09	0.22	0.26	0.29	0.23	0.09	-	-	1.17	0.70	1.88	7.52	4.54	6.03	4.20	8.39
Sadiqia	1,073,391	122	137	0.20	0.30	0.34	0.22	0.35	0.83	0.59	0.61	0.48	0.25	0.29	0.30	3.11	1.65	4.76	7.97	4.26	6.12	3.60	6.86
Bahawal	754,293	176	198	0.21	0.30	0.37	0.29	0.49	0.91	0.70	0.60	0.46	0.27	0.28	0.28	3.43	1.74	5.16	12.52	6.38	9.46	4.25	10.64
Qaim	41,571	170	195	0.01	0.02	0.02	0.01	0.03	0.05	0.05	0.04	0.02	0.01	0.01	0.02	0.20	0.09	0.29	13.36	5.92	9.65	5.25	11.08
Punjnad	1,388,500	149	171	0.33	0.48	0.63	0.50	0.83	1.56	1.23	1.03	0.74	0.45	0.45	0.45	5.85	2.84	8.68	11.60	5.66	8.64	4.20	9.88
Abbasia	250,699	120	134	0.05	0.08	0.10	0.07	0.08	0.18	0.14	0.12	0.10	0.07	0.07	0.07	0.70	0.44	1.14	7.71	4.83	6.27	4.25	6.99
Sum Punjab	**20,689,393**	**128**	**147**	**2.37**	**3.68**	**5.42**	**4.49**	**6.35**	**11.76**	**9.55**	**9.67**	**7.94**	**4.83**	**3.83**	**3.87**	50.09	23.66	73.75	6.67	3.17	4.92	4.12	7.36

C.I = Average cropping intensity   WA = water allowance cusecs per 1000 acres on basis of average season water demand. The symbol"-" indicates that canal is non-perennial.

The values under water requirements for Kharif and Rabi are not the simple total of column values. These are based on individual cropped area during each season (on the average) not on whole CCA basis. Same is the case with water allowance for individual Rabi and Kharif season. However, total annual water requirement and water allowances are compatible in computations and are based on total CCA.. Fordwah- a non-perennial if designed to perennial requires 1.88MAF water

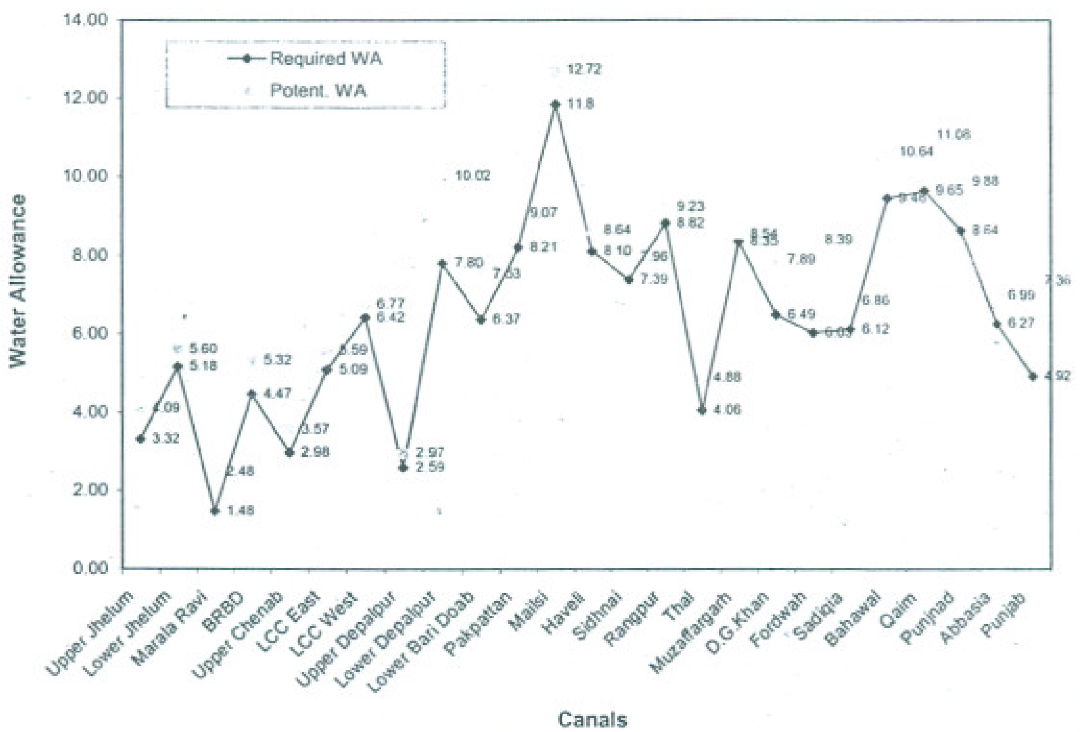
b. Potential Intensity

The potential cropping intensity (worked out at the highest value) is based on average cropped area during 1998-2002 for the command area of a canal under study. This reflects that cropping intensity is going to be observed practically to that high level in any of the years under study (Kharif 1998- Rabi 2002-03). The maximum potential cropping intensity is noted for command area of Bahawal Canal (198%). The potential cropping intensity on the average basis accounts to 147 percent (Table-5).

CROP WATER REQUIREMENT

The present crop water requirement at canal heads for both Kharif and Rabi seasons is displayed via Fig.2. This again bases on recent crop data (Kharif 1998- Rabi 2002-03). The Kharif water requirement of Pakpattan canal estimates to 4.98 MAF while for Punjnad it is 5.85 MAF. The LCC (East) and LBDC need 4.65 and 4.72 MAF, respectively for Kharif season only. The LCC (East) and LCC (West) systems require 3.48 and 2.48 MAF for Rabi season under the present cropping system. The total water requirements for Kharif at Punjab level comes to about 50 MAF, while it is 23.66 MAF for Rabi season. Under the existing cropping pattern the highest annual water requirement has been noted for Punjnad (8.68 MAF) and LCC (East) system (8.13 MAF). The Total annual water requirement of Punjab thus estimates to 73.75 MAF against 55.94 MAF as per water Apportionment Accord 1991 (independent of what has been actually short of Accord).

FIG. 3. WATER ALLOWANCE OF PUNJAB CANALS AT CANAL HEAD (Cusecs/1000 acres)



WATER ALLOWANCE

The annual water allowance (cfs / 1000 acres) under the present average cropping intensity (1998-2002) tunes to 11.8 and 9.46 for Mailsi and Bahawal canals, respectively, having 171 and 176% cropping intensity. It is notable that water allowance though linked with cropping intensity, not always depends on it. It rather depends on type of crops and cropping pattern, low or high delta crops and even on soil texture and weather elements. The required water allowance under the existing cropping pattern for different canal commands during Rabi and Kharif seasons is given in Table 5.

The water Allowance derived in this study may vary from the one worked out by some earlier workers. Hussain (2001) for example, reports Kharif irrigation requirement of 6.38 cusecs/1000 acres for LBDC., 5.46 for Rangpur, 6.79 for Fordwah, 6.54 for Sadiqia and 8.09 for Pakpattan, 8.23 for Bahawal, 8.25 for Mailsi, 4.97 for Muzzafar Garh, 4.92 for D.G. Khan, 8.94 for Punjnad, 5.73 for Abbasia and 9.09 for Thal canal. These values more or less differ from those worked out in this study. The difference may be due to:

- The period for which rainfall was considered
- The difference in best- estimate of the effective rainfall
- The number of years and time for which crop data values are taken care of
- The difference in canal commanded and cropped area reported
- The assumptions made for water losses

The water allowance on Punjab basis work's out to be 6.67 and 3.17 MAF for Kharif and Rabi seasons, respectively with annual water allowance of Punjab estimating to 4.92 cusecs/ 1000 acres. A look at the data reveals that at present cropping intensity of 128% in Punjab the annually required water allowance figures out to be 4.92, say about 5.0 against the in-practice water allowance of 4.12 cusecs.

At the potential cropping intensity (147%) in Punjab, the potential water allowance estimates to 7.36 cusecs/ 1000 acres. The trend in required water allowance, at the potential water allowance on different canals in Punjab is evident from Fig 3. The referred Fig also indicates the gap between the required and potential water allowance.

Now the question arises about water: from where the water should come? This is a God gift. The drought period is not always to prevail; it is a drought cycle span over 3-4 years. The question is, if surplus / sufficient rains start or snow melts, do we have storage capacity to capture all that, is the storage capacity of present reservoirs not dwindling? If new reservoirs are to be constructed, what capacity they should be of. To address all these issues first we at country level must think of our real crop water need with an eye on food security risk. None should connive at the dawn reality in context of water crises. We are Pakistani first and then Punjabi, Sindhi and Balochi. We must determine our real needs, develop water resources, construct dams, remodel canals and existing reservoirs in addition to formulating implement able and friendly policies in the best interest of Pakistan.

FINDINGS

- Present cropping intensity of the province has gone to 128% against the system designed at 65%.
- Against the existing / present cropping intensity, the provincial water requirement corresponding to Kharif and Rabi seasons accounts to 50.09 and 23.66 MAF.

- Crop water requirement of the province under the existing cropping pattern comes to 73.75 MAF against 55.94 MAF (Kh. 37.07, Rabi 18.87 MAF) as per water Apportionment Accord 1991.
- Under the existing cropping pattern water allowance is 4.92 (cusecs/1000 acres) against the current water allowance of 4.12 in Punjab.
- To shift cropping intensity form 128% to the potential intensity of 147%, the potential water allowance will have to be adjusted at 7.36 (cusecs/1000 acres).
- The potential crop water requirement at potential cropping intensity (147%) will shift to 110 MAF against 73.75 MAF worked out at the existing cropping pattern in province.
- The remodeling of canals has become imperative in addition to constructing new water reservoirs.

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AIRBLAST : A COMPREHENSIVE REVIEW

Dr. Syed M. Tariq*

ABSTRACT

Airblast is an undesirable by-product resulting from poor blasting. Airblast damage or annoyance is large related to factors such as blast design, weather, topography and human response. An understanding of the theory of airblast and the regulations relating to them will aid a blaster to operate at an acceptable profit level while confirming to regulatory specifications.

Airblast from a standard designed pattern can differ a lot from day to day and from one geographic location to another. The affecting factors governing those anomalies are atmospheric and topographic.

The main purpose of this paper is to aware the public and the blasting operators of the prevailing regulations relating to airblast, in the developed countries. It is extremely important to put such regulations in place here in Pakistan as well so that the airblast relating complaints can be minimized.

INTRODUCTION

When a blast is fired it is usually accompanied by a loud noise called airblast. It is an atmospheric pressure wave similar to compressional 'P' wave observed in ground vibrations. The pressure wave consists of high frequency portion that is audible and is the sound that accompanies blast. The low frequency portion, also called concussion, is sub-audible but excites structure and in turn causes a secondary and audible rattle within a structure. If the sound pressure is high enough, one or both of the sound waves can cause damage. Airblast generally is an annoyance problem which seldom causes damage, but may result in litigation between the operator and those affected.

Sound waves occur in a medium having the properties of mass and elasticity. In air, gas, molecules are distribute fairly evenly with a random movement. Under normal atmospheric condition air exerts a pressure of about 14.7 psi and weighs approximately 0.075 pcf. The mechanism of sound wave propagation is the transfer of momentum through molecular displacement from molecule to molecule. This disturbance of airblast is propagated through a compression wave that travels through the atmosphere. Under certain adverse weather condition, and poor blast design, airblast can travel considerable distances.

The velocity of sound in air at sea level and (32°F) is 1086 ft/sec. For each (10°F) increase in air temperature, the velocity increases about one percent. This is due to the fact that the random velocities of air molecules increase with temperature and thus make the transmission of pressure, pulse more rapid. When ever something moves faster than the speed of sound in air, it produces airblast. Blast designs should take into consideration the temperature of air because the speed of sound in air could be15% more in mid summer than in mid-winter when wind velocity is zero. With 50 mph wind in mid-summer and (30°F) in mid winter, the velocity of sound in air would differ up to 24%.

AIRBLAST AND NOSIE MONITORING

Sound can be monitored in two district units "Over pressure", i.e., air pressure over and above atmospheric pressure (usually expressed in pounds per square inch), or in decibels (db)

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which is an exponential expression for sound intensity that approximates the response of the human ear. Because of the wide range of over pressure, more than one billion units, the decibel

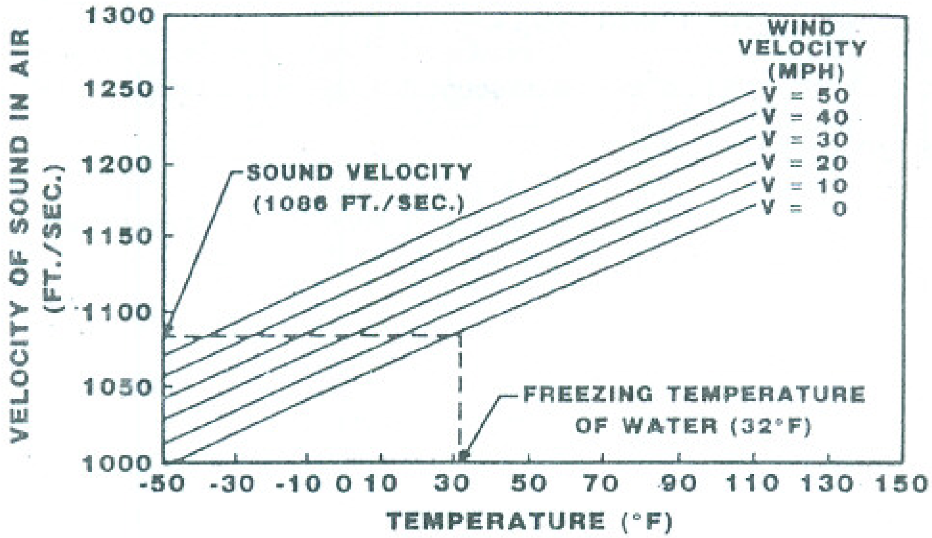

Fig. 1 Velocity of Sound in Air for varying wind Velocities vs. Temperature.

is usually used. As shown in figure 2, the decibel scale compresses (10^{-7} to 10^{0}) range of pressure amplitudes to a range of 50 to 170.

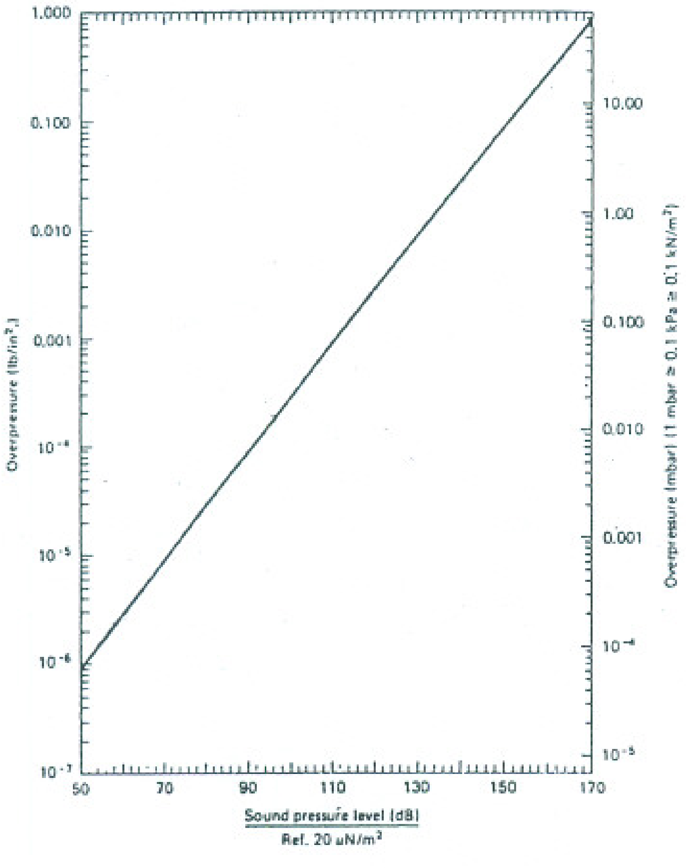

Fig. 2 Airblast level conversion and equivalence (after Siskind *et al.*, 1980a).

The decibel is defined in terms of over pressure by the following equation :

$$dB = 20 \log (P/P_o)$$

Where ;

dB = Sound level in decibels.

P = Over-pressure in p.s.i.

P_o Over-pressure of the lowest sound that can be heard (2.9×10^{-9} p.s.i.).

EFFECT OF WEIGHTING SCALES

Different weighting scales are used to measures sound levels ; however they do not respond equally to both high frequency pressures called sound and low-frequency pulses (1 to 30 Hz) that excite structures. The scales are designated A, B, C and linear and differ essentially in the ability to measure low frequency sound. The A-scale corresponds most closely to the human ear and discriminates severely against the low frequencies. The B-scale discriminates moderately and the C-net work only slightly while the linear network measures all frequencies. Figure 3 presents the frequency spectra or the response of transducers for the commonly used weighting scales.

Air pressure fluctuations that occur at frequencies below 50 Hz are recorded below their field value by "A" or "C" weighting scales. These are adequate for studying hearing response but shall not record the information necessary for correlation with structural response. "Linear" system that record accurately the pressures in both the structurally critical range 5 to 20 Hz, and the range critical for human hearing, are necessary in critical blast monitoring situations.

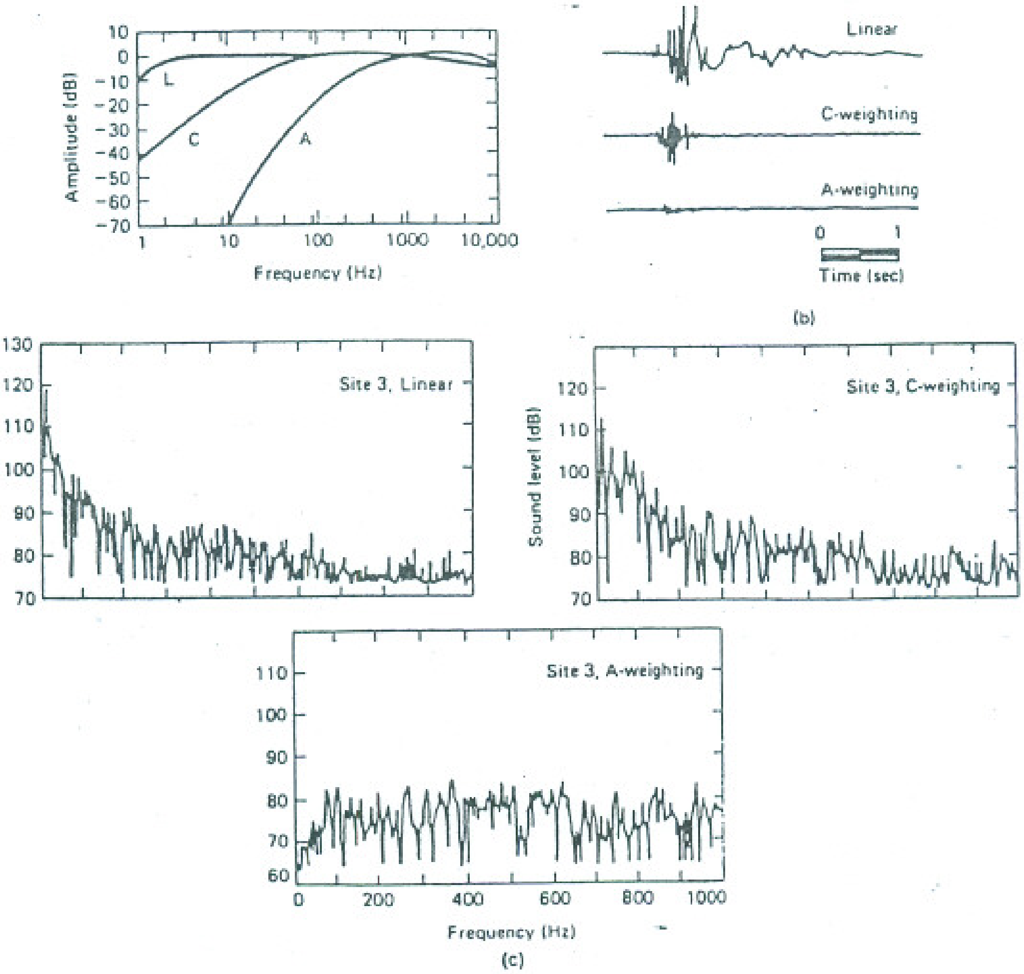

Fig. 3 Effect of Weighted Filtering on Airblast Records (a) Weighting scales ; (b) Time instances ; (c) Fourier Frequency spectra (After Siskind and summers, 1974).

LEGAL LIMITS

The legal limits for airblasts were for a long time set at 130 dB. However, as a result of work published by the Bureau of Mines in 1980 (RI 8485), entitled "Structure Response and Damage Produced by Airblasts from Surface Mining", these limits have been revised.

Damage to structures has been shown to be directly linked to the peak pressure of the airblast profile and also its frequency content. For a standard pressure the structural response of a dwelling or other building can be shown to be dependant on the frequency of the pressure pulse. For example consider^ house with approximate dimensions of 40 ft square, its resonant frequency in air could be given simply as :

$$Fr = Co/L$$

Where Fr is the resonant frequency, Co is the velocity of sound in air and L is the dimension of the structure. For a quarter wave length the frequency can be given as follow :

$$F = Co/4L$$

For an approximate sound velocity of 1000 ft/sec., we have a resonant frequency of 25 cps and a quarter wave length frequency of around 6 cps. These values agree well with the Bureau's findings which showed that residential structures are most susceptible to excessive stresses from airblast energy within the frequency range of 5 to 25 Hz.

The Bureau also reported that the Airblast were found to contain significant amounts of energy below this range (as low as 0.5 Hz) as well as above 200 Hz the (the normal measurement system maximum). Due to low frequency pressure loadings having a long wavelength, a long loading duration is also incurred allowing extra possible damage to occur. Thus this factor is now taken into account in the new regulations effective 1983 as follows.

Extract from O.S.M. Regulations ($ 816.67)

AIRBLAST LIMITS, Airblast shall not exceed the maximum limits listed below at the location of any dwelling, public building, school, church, or community or institutional building outside the permit area.

Measuring System Response	Recommended Safe Level
0.1 Hz Low f cutoff *	134 dB
2 Hz Low f cutoff	33 dB
5 Hz Low f cutoff	129 dB
"C" Weighted-slow *	105 dB

* Only when approved by the regulatory authority.

If necessary to prevent damage, the regulatory authority shall specify lower maximum allowable airblast levels than those mentioned above for use in the vicinity of a specific blasting operation.

Referring to the table above ; the 0.1 Hz Low frequency cut off system is basically a research tool and is too sensitive to wind noise to be used practically as a measuring device in the field for standard production blast monitoring. The "C" weighted-slow device on the other hand has a low frequency cutoff of 31.5 Hz. It also differs from the other three systems in that it integrates the airblast energy over a period of approximately one second, ratfier than responding to single short-duration airblast peaks. It is therefore recommended that neither of these two systems should be used.

In must be noted that RI 8485 states (page 57) that the potential damage from these "safe" levels corresponds to essentially zero (less than 1 percent chance probability of superficial damage). RI 8485 further states (page 60) that there is a consensus among many studies that damage becomes improbable below approximately 140 dB. However, it is always prudent to take into account that not all residential structures are well designed and/or well built.

O.S.M. defines the regulations concerning airblast monitoring as follows :

MONITORING : (i) The operator shall conduct periodic monitoring to ensure compliance with the airblast standards. The regulatory authority may require airblast measurements of any or all blasts and may specify the locations at which such measurements are taken.

(ii) the measuring systems used shall have an upper-end flat frequency respose of at least 200 Hz.

CAUSES OF AIRBLAST

There are five main causes of air blast over pressure ;

1. **Air pressure Pulse (APP) :** Conversion of ground displacement to air pulse at free rock surfaces.

2. **Rock Pressure Pulse (RPP) :** Produced from the vibrating ground.

3. **Gas Release Pulse (GRP) :** Gas escaping from the detonating explosive through rock fractures.

4. **Stemming Release Pulse (SRP) :** Release of high pressure gases to the atmosphere through the blast hole after the stemming has been pushed out.

5. **Detonating Cord Pulse (DCP) :** Release of high pressure gases to the atmosphere by detonating and trunk line exposed on the surface.

The first pressure pulse that arrives at the recording station is RPP generated by the vertical component of ground motion, summed over all the areas. A relationship given by Wiss, between the vertical ground motion and RPP is :

$$RPP = 0.0015\ V_z$$

Where V_z = Vertical component of ground motion.

If the vertical component of ground motion was measured to be 1.5 in./sec.

Then R.P.P. = 0.0015 (1.5) = 0.00225 P.s.i.

$$dB = 20\ lo_s \left[\frac{0.00225}{2.9 \times 10^{-9}} \right] = 118.8$$

The APP is the second pulse to arrive via air at the measuring station. APP arrive much later because of the lower propagation velocity of rock.

The GRP, SRP and DCP are the main contributors to airblast damage and complaints. However, they are the easiest to measure, with the use of high speed motion photography and are the most controllable in blast design.

ATMOSPHERIC AND TOPOGRAPHIC EFFECTS

In Airblast Control for blasting, the airblasting from a standard designed pattern can differ drastically from day to day and from geographic location to location, even in the same rock horizon. In addition the distribution of that airblast can differ enormously. The affecting factors governing these anomalies are atmospheric and topographic. As it is given below, these factors can, in a wide number of instances, be related.

Atmospheric Effects

Variations in airblast patterns and intensities due to atmospheric effects can be attributed to two totally different atmospheric phenomena, those of atmospheric thermal gradient anomalies, and wind.

Inversion Layers

The atmospheric thermal gradient anomalies which affect blasting air over pressure consist primarily of Atmospheric Inversion Layers. Normally the earth's atmosphere cools at the rate of approximately 4 deg, per 1,000 ft. However under certain conditions such as approaching warm and cold fronts warmer air is forced upwards over colder, near surface, air producing an inversion layer.

Effect of Inversion Layers on Surface Blasting

In surface blasting under normal thermal gradient conditions airblast over-pressure in the from of noise is dissipated upwards and outwards in a hemispherical fashion. However, under inversion conditions the thermal gradient is replaced by a sharp boundary. Due to the impedance miss-match laws, a large proportion of the energy is reflected back from this layer producing more, of a fixed height cylindrical dispersion rather than hemispherical dispersion. Under these conditions airblast pressure dissipate inversely with the square of distance from the blast rather than inversely with the cube of the distance.

For approaching frontal conditions, especially for approaching warm fronts the greatest effect will be noticed at a distance from the blast rather than close up to it, the minimum critical distance being approximately twice the height of the inversion boundary layer from the surface.

Obviously for localized inversions due either to topographic effects and/or a sharp temperature change such as experienced around sunrise and sunset this critical distance is negligible. Thus blasting in these conditions should be avoided at all costs if there are residential structures etc, (as prescribed by $ 816.67 paragraph (b).(1). (i) of 83 O.S.M. Regulations) in the vicinity of the mine site.

Effect on Inversion Anomalies on Underground Blasting

The release of excess pressure created by underground blasting to the surface atmosphere is generally by two types of openings ; Vertical i.e. shafts, and horizontal comprising drifts and addicts.

Surface airblast problems from underground blasting arise when insufficient volume of excavation and/or short distance to surface exists.

For the case of Horizontal openings-medium to high level Inversions tend to have minimal effect on peak air over-pressure's, wind direction has far greater effect. However for unobstructed vertical openings the opposite is true. For this type of opening airblast is partially reflected directly back down by all types of atmospheric inversion. Wind direction and velocity has little effect except in combination with medium level inversion layers.

WIND CREATED ANOMALIES

1. Elliptical pressure distributions

The effect of wind on hemispherical air over-pressure distribution is to modify its shape to that of an ellipse. The can be simply explained as a compression of over-pressure "isobars" upwind and a complimentary stretching in the down wind direction. As a result of this egg shaped-peak air over-pressure contours are obtained whose axis is co-incident with average wind direction. Subsequently the peak air over-pressure measured at a specific location may vary widely, dependant on wind direction and velocity at the time of blasting.

Although this general theory agrees with the results of extensive monitoring carried out by the Bureau of Mines, maximum wind velocities only account for a small fraction of the velocity of sound in air (approx, 1087 fps), and subsequently cannot for the extremely large and extensive modification that can occur.

2. Direct Wind Effect

This anomaly is due to complex wind phenomena/ground effects. For the case of any physical movement directly into wind a deflection upwards occurs, resulting eventually in the tailing backwards of the air over-pressure front. The degree of deflection is directly dependant on the wind velocity and is in the form of a log/log relationship. This phenomenon can be attributed to drag effect at the ground surface resulting in an increasing velocity profile upwards with associated turbulence above critical wind shear velocities. Thus peak air over-pressures can be dramatically reduced upwind of a blasting site by only moderate wind velocities.

For the case of any physical movement downwind, the reverse applies and any movement including over-pressure tends to be deflected back downwards. Thus dramatically increasing peak air over-pressure levels downwind of the blasting location for again only moderate wind velocities.

It is therefore prudent to avoid a choice of sites upwind relative to the prevailing winds of a residential community, and also to avoid firing when wind conditions are such that Wind direction is towards moderately close residential structures and of moderate to stiff speed. In cases where the first condition is not met, it should be considered wise to keep blasting operations sufficiently ahead of excavation and haulage so that blasting can be scheduled only for favourable weather conditions (including favourable wind direction).

Topographic Effects

1. Topographic Variation

Hemispherical expansion of the air over-pressure wave at ground surface is only directly applicable without modification for flat ground. In the case of variable terrain two different situations can arise : Firstly, for areas shielded by the topography peak, air over-pressures will be reduced. Secondly, for elevated areas in direct line with the blasting site, peak air over-pressure will tend to be generally higher than flat ground due to the absence of ground attenuation effects. Greatest differences will be obtained for the first case.

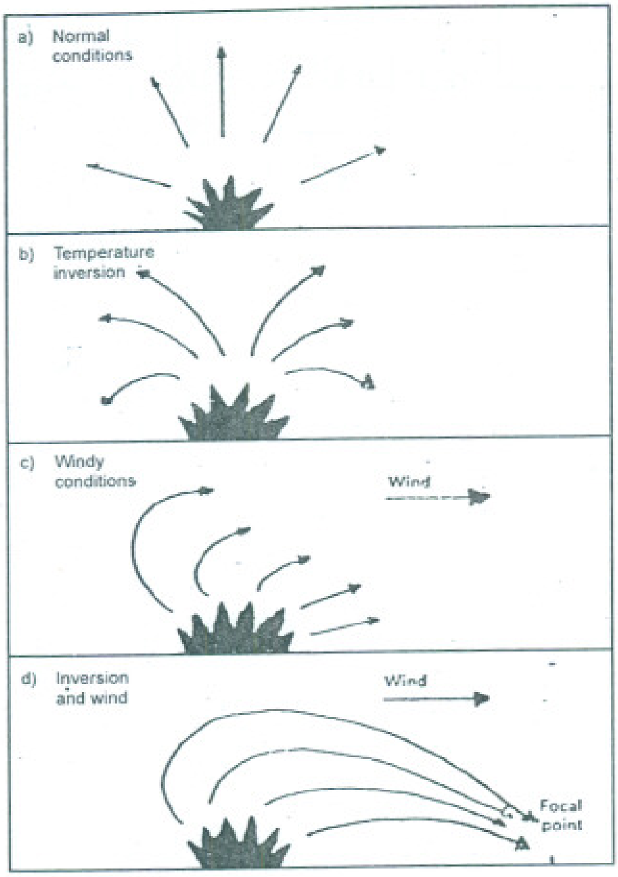

Fig. 4 Wind Created Anomalies

2. Vegetation

The general effect of vegetation in direct line between any location and the blasting site is that of a muffler. However, the degree of muffling is dependant on thickness, height, and type of cover and can only be assured of reducing peak air over-pressure by up to 10 dB. Seasonal changes can also occur especially, with deciduous foliage. Evergreens tend to have more of a constant modification.

3. Topographic Modifications for atmospheric Conditions

In addition to shielding residential structures etc., from air over-pressure topographic shielding can have unforeseen consequences if a medium height inversion layer downwind conditions exist. Such conditions could exist for instance with a rapidly approaching warm front with closely spaced isobars. In these conditions the structure may no longer be shielded by its surrounding topography and may experience extraordinary high peak air over-pressure levels. In these conditions severe complaints and even legal suites may be issued by neighbours who may never have complained before.

4. Acoustic Reflection and Channelling

In mountainous regions airblast may be reflected off mountain and steep hill sides at areas which are not in direct line with the blasting site. Bare rock offers the most efficient reflection surface, and short grass the second. The planning of tree groves can reduce these problems especially if mining in the area is expected to continue for extensive time.

Airblast can also be channeled along valleys resulting in reduced attenuation due to the formation of quasi-plane waves rather than hemispherically expanding wave fronts.

SCALED DISTANCES

In contract to ground vibrations, airblast is scaled according to the cube root of the charge weight, that is :

$$D/w^{1/3} = K$$

Where

D	=	Distance (ft.)
W	=	Maximum charge per 8 clay (lb).
K	=	Scaled distance value.

Cube root scaling is appropriate for airblast, that is the observed data conform to cube root scaling rather than square root scaling.

CONCLUSION

This is correct to say that we all become used to various noises such as there produced by aircraft, traffic, machinery at workplace and blasting etc, and becomes more tolerant to these noise. When a new quarry on an open pit operation commences, the blast noise is "frightening" and makes life very difficult for nearby inhabitants and for the operators as well.

Public relationing plays an important part in mitigating airblast related complaints. It has been found that continues monitoring helps a lot in overcoming many problems as people feel satisfied if instrument are installed near their houses for continuous monitoring.

In Pakistan, as the quarries are approaching towards the residential areas or towards some sensitive installations, the level of complaint are also increasing. There is an urgent need of proper airblast and ground vibrations relating regulations to be put in place so that these airblast relating complaints are properly looked at and resolved according the legal limits imposed.

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FLEXIBLE DATA-DRIVEN SIMULATION TOOL FOR THE EXTENDED ENTERPRISE OPERATIONS

By

Usman Saeed Khan*

Abstract

To efficiently manage the business in Extended Enterprise enough support tools are required. The group of companies in the Extended Enterprise can make desirable profit only when each company matches it's pace with the pace of it's customer and maintain this pace till it is the part of the supply chain. To synchronise the pace and to accommodate the changes in the Extended Enterprise to reach upon decisions quickly, the paper suggests a flexible data-driven tool, which is based on simulation. The tool helps to measure the suppliers' capabilities and the effects of the suppliers on the whole supply chain, thus it helps to optimise the supply chain. The paper takes simulation into detail and describes how the benefits can be extracted out of the simulation and simulation to be the most effective platform to observe the Extended Enterprise operations.

Make vs. buy is always been a question for the companies. But, we have seen in the last few decades that how the stress on the vertical integration has reduced. Reason which leads to this is, that the companies have realized that its better to concentrate on few selected areas than managing a wide spectrum of activities. In this way, the companies can optimize their resources for their core competences. Why to take the hassle of making components, which are in better quality and are cheaply available than the ones that they make on their own. This has given rise to the Extended Enterprise, where different companies have come together to establish a network for mutual benefits [1]. This has shifted the focus from managing the manufacturing to managing the supply chains. The competition is no more between the companies it is between the supply chains. The whole structure of Extended Enterprise is based upon the foundation of supply chain. Only those companies who have efficient supply chain management can stand and compete in Extended Enterprise, otherwise they will be flushed out. Automobile, aerospace, electronic industry and many others are now based upon the Extend Enterprise business model. The supply chain is normally defined by the product structure. The more complex the product more lengthy and complex will be the supply chain. Maintaining such a supply chain is not an easy job, as one has to consider the performance of each supplier and its effects on the whole supply chain. Switching from one supplier to a new supplier could affect the whole chain. The new supplier may offer a better quality and cheap price but it may be situated in some distant foreign country. This would change the whole supply chain structure. Therefore, adaptive and flexible tools are required which can easily accommodate the changes of supply chains in the Extended Enterprise and help to achieve correct decisions in a short time.

1. Simulation as an Option

Supply chains are complex operations and their analysis requires careful defined approach. Efficient management of activities offers opportunities in terms of cost and lead-time reduction and improved quality. The competition implies that quality, time and cost must be improved successively in order to stay profitable. Simulation modeling is an effective tool, which helps in design, evaluating and optimizing the supply chains [2]. It is used to deal with the stochastic aspects of the supply chains. Though, the importance of simulation for supply chains is realized quite late but now it is progressively used to tackle supply chain problems.

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2. PROPOSED SOLUTION

The aim was to develop a re-configurable data-driven flexible tool, which would be based on simulation. It would help the company to infer either about the whole supply chain or a particular supplier in the long run. In late 90's, the use of simulation was started for supply chain analysis. Still most of the supply chain simulations are problem focused (i.e. problem solving tool) and to the author's knowledge, simulation has not been used for the Extended Enterprise as decision-making tool. The simulation has been made flexible by linking it with the database. It would centralise the data management, as a single source would be providing data for different purpose in the company. This would avoid data redundancy. The main idea behind such simulation was that when suppliers quote their performance measures, these performance measures would directly be used in the simulation to see the supplier's compatibility in the supply chain. This would make decision-making process more quick and efficient. The other idea behind the simulation construction was that it would also serve as a benchmarking tool, as it would allow the company to compare its performance measures with other companies.

The paper first takes on to the simulation model development. It gives details of simulation construction and assumptions, which were used for the modelling purpose. Then, it covers the verification of the model. The results of the test for which simulation has been checked are also encrypted, so the reader gets a better understanding of the model performance. The model is then statically analysed to see the effects of randomness on the model output. As the data of actual system was not available, therefore the proper validation could not be done. But few words of the general validation and intangible aspects of the validation are mentioned for the reader's interest. The paper is concluded with the future prospects of the flexible data-driven simulation, giving how the results of the simulation could be made more accurate and reliable.

3. FLEXIBLE DATA-DRIVEN SIMULATION MODELLING

A decision support tool was developed based upon "*Discrete Event Simulation*"[1]. This simulation would help to see different scenarios and compare the cost, the time and the throughput of different suppliers. It was made with an idea that the simulation engine would get the information about the performance measures of different suppliers directly from the database software. This database software could be any, a world wide web based database where different companies could come through internet and quote their performance measures for a specific component or the whole product which they wished to supply or it can be company's internal database where it records the performance measures for different companies, which could supply the desired components. Here the idea was only scratched for companies' internal database where MS Access was used to develop the database, but it could be easily exploited for the Internet servers, as companies maintain such Internet based databases for product or component quotes, where interested companies could plug in and provide their realistic details. Such linking of simulation with the Internet databases will provide a great deal of time saving and better information management and flow. Simulation is constructed using three distinct technologies professional simulator Arena 5.0, Visual basic Application for Arena and MS Access 2000.

The idea was to construct the model for a complex product where supply chain would go up to second or to third tier suppliers in the Extended Enterprise. For this purpose an aerospace industry, Rolls Royce, was picked and their product TRENT-800 jet engine was used. Picking up an aerospace industry also gave another benefit that today's aerospace industry represents a true Extended Enterprise. One of the main assumptions used to build the model was that the

[1] Discrete even simulation is the one in which change occurs only at separated points in time [3].

design phase for the TRENT-800's components and sub-assemblies was ignored and the processing time specified at each supplier level only counted for the actual manufacturing time and it did not include the design phase time. This was done to avoid the time variation in the entities (component or product), as the time for the first entity would different than the entities following it. The simulation was only built for the regular production of components/sub assemblies.

TRENT-800 jet engine is second to the top in the TRENT product family. It was broken down into main sub assemblies and then further sub-sub assemblies, shown in the figure 1, with this assumption that supplier could provide either a sub-sub assembly or a whole sub assembly rather providing a single component or components of that assemblies. This assumption was made for the purpose of simplifying the model. All the value added and non-value added time events and entity creation were described by the exponential distribution. All the simulation was based on hypothetical data and distributions, as the data history for the product was not available. Exponential distribution was used to create the coherence and simplicity in the simulation model. This distribution could be changed easily on knowing the actual data distribution.

The whole product structure was divided into three levels i.e. final assembly, first tier suppliers (sub-assembly) and second tier suppliers (sub-sub assemblies), shown in figure 2. The Input to final assembly was the output of the first tier suppliers and similarly the input to the first tier suppliers was the output of the second tier suppliers. The input to the second tier suppliers i.e. the raw material for the second tier suppliers was created by using Create module of Arena. The base operational unit was hours, which means that all the input to the simulation engine is given in hours. At all the intermediate levels, all the arriving components were first matched, so that the processing starts only when all the required components have arrived. A proper batch was created, which was then sent to the processing area (processing time was taken as value added time). After processing, the output product was sent to next customer in the value stream. Transportation time was taken as non-value added time.

One of the main reasons for using Arena simulator is because of its ability to allow

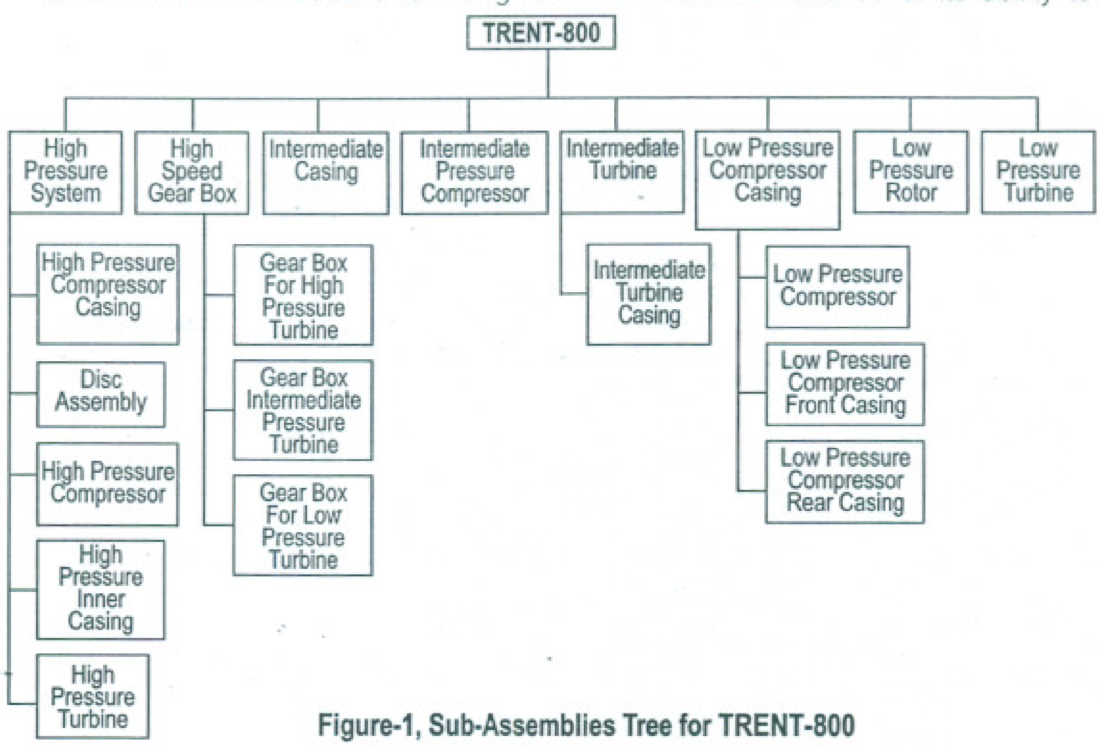
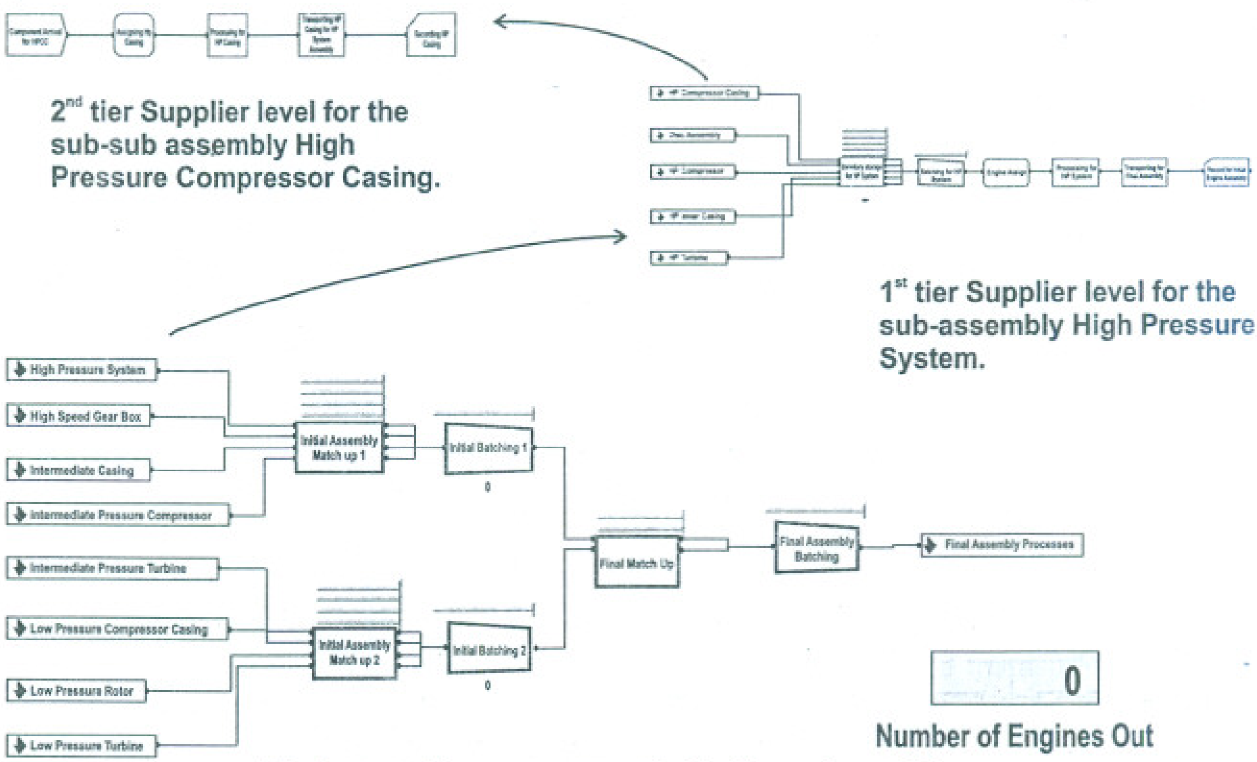


Figure-1, Sub-Assemblies Tree for TRENT-800

interaction between procedural languages e.g. C++ and Visual Basic, and simulation language

SIMAN. Visual Basic was used to develop communication between the Arena simulator and the database. Arena has provided different Visual Basic objects, which allows interaction at different events during the simulation run. The coding was done for the event when Arena initializes all the run-time parameters. An ADODB object was used for accessing the MS Access based database. A sample database was built on the MS Access for the simulation purpose, which incorporated the details about manufacturing lead-time (value-added time), transportation time (non-value added time), components arrival time, and order quantity. A user form was created a front end to present the data. A complete movability was placed so that the user could upload any value to the simulation to note down the respective performance. All these developments are the first step towards the idea of "Dynamic data-driven simulation", where the expected changes in the supply chain can be put in a single run. For example switching to a new supplier, out-sourcing a component, which initially was made in-house, market dynamics, production changes, component design changes etc. It would be of great help, as it will demonstrate supply chain performance during the period of changes. Therefore, the necessary measures could be taken in time to minimise the effects of changes and smoothness could be maintained in the supply chain.



Final assembly area represented in the main model

Figure-2, Supply chain architecture simulated in Arena

4. VERIFICATION

Verification is the process of ensuring that the simulation model built behaves the same as it was wished for according to the modelling assumptions made. Model verification process is generally done in two steps. First step requires the removal of all error messages, which occur when Arena is initialising the model for the run-mode. This can be termed as debugging the model. If any error occurs, while initialising, an Arena error window is opened which not only tells the reason for the error but also locates the position of the error so the user can easily debug the model [3]. All such kinds of obvious errors are removed while making the model. Object of this chapter is not to deal with such kind of error messages.

The second step of model verification deals with the problems, which are not that obvious. By this the author means the problems, which are apparently not visible. The model seems to work properly for one set of control values and all the results are okay, but the point when control values are changed a little, the model shows extra ordinary deviation from the intended behaviour. For this, different tests have been applied to the model to check its behaviour in different states, especially at the extreme conditions. The author has made use of basically two categories of tests to cover the two extremes. They are:

1. Single entity scenario and
2. Model overloading.

4.1. Single entity scenarios

The single entity test was checked for two different scenarios: firstly, checked for the single entity output and secondly, for the missing entities i.e. zero entities were placed in combination with single entities. First, all the value added time, non-value added time and entity creation time were set to constants. Therefore, the total lead-time of the supply chain would be predictable and it would also help to identify the critical path. Single entities were created at all the creation points by setting the order placement to one. The model was run for enough time so that all the entities were created and had enough time to process. The animations, which were created, had provided a good understanding of the model. It is always recommended to create animation before starting the verification process.

4.1.1. Scenario 1

The purpose of this test was to see that all the entities were created properly and to observe the behaviour of every entity in the supply chain as they moved around. As the value added time and non-value added time were constant, therefore the lead-time for each branch in the supply chain would be predictable. It was observed that, before running the model, High Pressure Turbine –High Pressure System – Final Assembly made the critical path, as they caused the longest lead time. The total time defined for these levels were:

High Pressure Turbine = 1752 hours
High Pressure System = 2136 hours
Final Assembly = 1536 hours

The Total time was the sum of value added time and the non-value added time. Therefore, the lead-time for the supply chain was expected to be 5424 hours.

On going through the reports after running the model, it was evident that simulation successfully passed the test, as output of the run was a single engine The results for number of entities going in the processing modules and number of entities coming out of the process module are displayed below which verify that the simulation successfully passed the single entity test and it also shows that none of the entities were neither in the middle of processing nor in the middle of transportation.

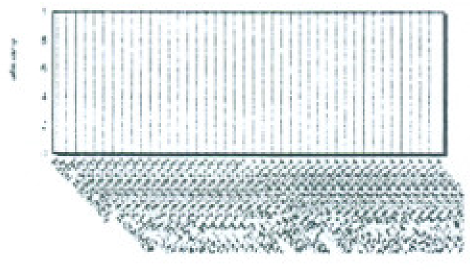


Figure 3, Number of entities going in.

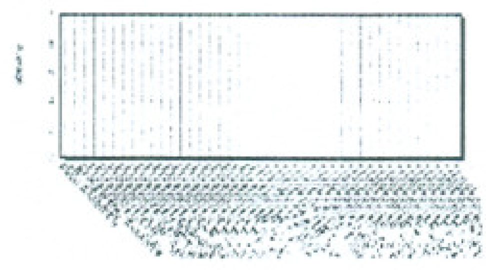


Figure 4, Number of entities going out.

As for the total lead-time for the TRENT-800, it came as expected i.e. 5424 hours. See the following calculation.

<u>High Pressure Turbine</u>

Average Value Added Time = 1680 hours
Average Non-Value Added Time = 72 hours
Total Time = 1752 hours

<u>High Pressure System</u>

Average Value Added Time = 1680 hours
Average Non-Value Added Time = 456 hours
Total Time = 2136 hours

<u>Final Assembly</u>

Average Value Added Time = 1440 hours
Average Non-Value Added Time = 96 hours
Total Time = 1536 hours

<u>Average Lead Time = 5424 hours or 226 days</u>

From this, one other thing is visible that user can make use of entity waiting in every queue and calculate the slack related to all the non-critical entities. This would help to optimise the supply chains by providing user the earliest[2] order placement and latest[3] order placement time.

4.1.2. SCENARIO 2

This test could be considered a part of single entity test. In this test, zero entity was mixed with the single entity and the result was predictable, as no final engine would be produced because each entity was required to complete the engine. Therefore, placing zero entity meant that few of the sub assemblies would be missing to complete the final assembly. The Intermediate Casing and Low Pressure Rotor were set to zero and all the others were set to a single entity. It was expected that all rest of the sub-assemblies would be settled down at Initial Match up modules of the Final Assembly and won't proceed further.

On running the model, the results came as expected. All rest of the entities hung up at the match module, as told, and no engine was produced in the whole run. One see in the figure below that the total time for the intermediate casing and Low pressure Rotor is not appearing because these entities were not created.

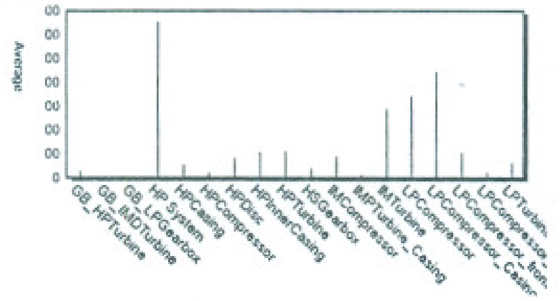


Figure 5, Total time of the entities.

4.2. MODEL OVERLOADING

This is the final test, in which the model was overloaded. By overloading author means that an extreme condition was created by changing few of the entities creation time so that long

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[2] Earliest order placement time is defined as the earliest time a customer can place an order without affecting the critical path.

[3] Latest order placement time is the latest time a customer can place order with the supplier without causing a delay in lead-time.

queues were created in the system at different points without changing processing and transportation timings and as well model was run for a very long time. For this, single entity creation was replaced by the infinite entities so that entities keep on producing during the whole run. The model run length was set to 200,000 hours that is approximately 23 years time. The values, which were used for the Constant Values Test, were the same values, which were used as the means for exponential distribution. The reader should keep in mind that lead time for the constant value test i.e. 5424 hours equals to 226 days, and it was expected that the average lead time for this run would be the same. The critical path was considered to be the same as constant value test path and but here other paths like Low Pressure Compressor – Low Pressure Compressor Casing – Final Assembly and Intermediate Turbine Casing – Intermediate Pressure Turbine – Final Assembly also have higher probability to become a critical path because exponentially distributed random numbers are generated to define the time for these sub-models and the difference between the sum total of these paths was not much.

After running the model, average total time for each sub-model was calculated by adding the average value added time and non-value added time for that model. And the average lead-time for the supply chain model was calculated by adding together the total time of the sub-models in the critical path. Lead-time calculation is shown below.

High Pressure Turbine

Average Value Added Time = 1924.36 hours
Average Non-Value Added Time = 50.30 hours
Total Time = 1976.66 hours

High Pressure System

Average Value Added Time = 1978.53 hours
Average Non-Value Added Time = 473.88 hours
Total Time = 2452.41 hours

Final Assembly

Average Value Added Time = 702.54 hours
Average Non-Value Added Time = 53.52 hours
Total Time = 756.04 hours

Average Lead Time = 5183.11 hours or 216 days

The average lead-time was approx. equal to the lead-time for the constant value test despite at few of the sections there was very high WIP, which one could the see in the queue graph given in figure 6. This proves that the simulation is verified as it successfully passed the test.

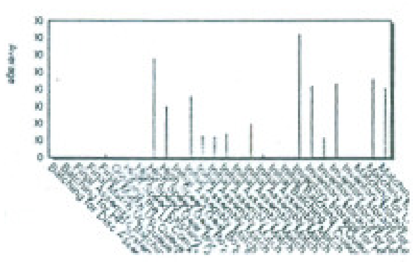

Figure 6, Number of entities in the queue.

Statistical analysis:

5. Statistical Analysis

The real life events are totally random e.g. consider a queue in the post office, the next customer can come and join the queue either in 1 minute time or may come after 10 minutes. This is picturized in simulation by giving the random inputs. Though, it provides the solution to the problem but this solution turns to curse as giving random input will lead to the random output. That means the output of the simulation would not be predictable. Making a single run of the simulation model wouldn't tell any thing about the degree of randomness attached to the model. Hence, the randomness of the simulation model can be calculated by making a number of independent replications. Before the author goes into the depths of simulation model sample collection and calculating the statistics for the sample, it is needed to differentiate between the terminating models and non-terminating models or steady-state simulations.

Terminating System: It is the one in which model dictates as the specific starting and stopping conditions as a natural reflection of how the target system actually operates [3]. For example, a super store opens every morning at 8:00 AM with no customers present, and closes its doors at 10:00 PM and operates till all the customers are flushed out.

Non-Terminating Model or Steady-State Simulation: It is the one in which model doesn't have any specific starting and ending point and entities, which need to be measured, are defined in the long run [3]. As there is no particular starting point the initial conditions of the model doesn't matter. For example, airport operations are continuous; it never really stops or restarts, so a steady-state simulation might be appropriate.

Supply chain operations are complex. It can either be taken as terminating model or the steady-state model. Terminating model in a sense, when a specific order quantity is observed in the supply chain e.g. an order of 50 engines order is placed at the supplier, and non-terminating in a way when companies are in contract not supply a specific number of quantity but to provide a continuous supply till the contract period ends e.g. an Automobile manufacturer makes a two year contract with some company to provide plastic front bumpers for their new model. No doubt, the supply chain operations are totally debatable, but author thinks that it totally depends upon the analyst that how he or she is defining the supply chain. Supply chain for the TRENT-800 has been defined as steady-state simulation because it is assumed that if Rolls Royce opt for outsourcing then it would make a timely based contracts with its suppliers, where a single supplier would provide the desired component i.e. the sub-assembly in this case, during that time, rather than fixed number of quantity based contracts. Though, in whichever way the model is taken either a terminating model or the steady-state model the model output wont be affected, but model core perception and its behaviour would totally be changed. Therefore, steadiness would act as one of the main and the most important assumption. Assuming the simulation to be a steady state served another purpose as well that is even in reality supply chain would take some time to reach the steady state. The steady state would represent when component manufacturing would be in full swing and no component design phase would cause the delay. It also supports the initial assumption that supply chain is built for components which are ready to manufacture and there would be no change in design which would cause delay to the supply chain operations and set a new steady-state for the operations. Though, in reality change in component design normally occurs may be for the improvement purpose or may be because of some new manufacturing technique. Such changes can be compensated by re-running the model with either new processing time or new component arrival time depending upon the requirements.

The strategy which was used for the simulation output analysis was to collect the sample of the simulation run (i.e. replicating the model), then observing that statistics which were calculated by the Arena for the sample. These replications should be statistically independent and identically distributed (IID). It means that all the replications should be independent and should not have any sort of relationship with any other replication. 95% confidence interval is parameter used for the measuring the randomness. 95% percent confidence interval is the most important measure as it gives the "point" estimate as well as an idea how precise this estimate is [3]. It could be defined as an interval, which is centred on the sample mean. If 100 of such samples are collected then each would be having its own interval and 95 percent of the interval would cover the mean.

Calculating the 95% confidence interval for each variable used in the simulations would not be appropriate. Therefore, a variable was needed to define which gives the performance measures of all the variables. Lead-time was the main performance measure for the supply chain, so author has divided the total lead-time into *value added lead-time* and *non-value added lead* for the simulation. The critical path was same as in the verification tests i.e. High Pressure Turbine – High Pressure System – Final Assembly. Though, total lead-time, which would be the sum of total value added time and total non-value added lead time, could be defined. Though, that would give overall variation of the simulation, but author on purpose had taken total value added and total non-value added lead time for the supply chain separately as it would provide better understanding by telling whether the value-added time or the non-value added time variables would be causing more variation. Similarly, such variations for each supplier could be noted, as each supplier in the supply chain makes a single separate unit and when a real time data is being used, this would identify supplier, which would be causing the most variation

Other than lead-time, supply chain throughput was also used for the variation analysis. Throughput means the number of engines produce for one replication. This would be very helpful, as it would tell the analyst to see how the engines produced vary for the single frame of time.

5.2 Warm-up Period Consideration

As simulation was considered to be a steady-state simulation, so warm-up period was the biggest issue in hand. Warm-up period is defined to be the time from starting the simulation to the time when steady state is achieved. The model starts out empty and idle that means there is no entity in the model and all the resources are at zero. This would be an initial condition for the terminating model, but for the steady-state, initial condition doesn't matter [3]. This would cause an error in the end results. Reader must be thinking that empty and idle state should be okay, as this is the way things might start in the actual supply chains. This might be okay for the fixed quantity based contracts because if the contract is refreshed, things would start from the beginning again. But in the timely based contracts, it doesn't matter how the things start. It all depends upon how the things are maintained.

The output analysis is conducted in two steps. First step is to identify the warm-up period and the second is with warm period defined for the same number of replications, it would truncate the run to minimise the effect of warm up period. Both steps would give an enough idea about the variation in the simulation model. Here goal is not to reach any specific target of variation, it is just to know the amount of variation related to the model. It totally depends on the analyst that how much tolerance he or she would allow for the variation. And then would do the number of replications accordingly. No specific comments can be made about the system variation as system is totally based upon the hypothetical data. But when true system data is utilised, important inference can be made out of it.

5.2.1 Step 1

"Step one" was done to locate the warm up period. The model was run for 90,000 hours, which is a little more than 10 years. Initially 50 replications were made for the model, so that warm up was correctly located when all these 50 replications converge to a single state. The results obtained for the run are given below in the tables 1 and 2.

Time Persistent	Avg	Half Width	Mini. Avg.	Max. Avg.
HPS_NVAleadtime	502.92	15.16	393.06	647.10
HPS_Valeadtime	3869.3	98.19	3193.3	4846.3

Table 1, Total value added and non-value added time results for the 50 replication run without the warm up period.

Number Out	Avg	Half Width	Mini. Avg.	Max. Avg.
Transportation to the Customer	102	2.89	76.0000	125.00

Table 2, Throughput results for the 50 replication run without the warm up period.

Reader can see that the 95% percent confidence seemed pretty reasonable, but all these values are corrupted due to the presence of warm up period. This would become more prominent when in the second step warm up period would be defined for the simulation.

The throughput of the simulation is not much affected with the simulation warm up i.e. steady state. It was presented just to show how the randomness affected the overall output of the simulation. It presented a range for the output, where the minimum average value i.e. 76, could be taken as an output of supply chain under pessimistic conditions, maximum average i.e. 125 as an output under optimistic condition, and average i.e. 102 is the most probable output under the normal conditions. Graph for the throughput is presented in the figure 9.

Reader can see warm up periods in the figure 7 and figure 8, which is due to the empty and idle state. On taking consideration of all the replications, for both total value added time and total non-value added time, 24,000 hours was taken as the end point of warm up period. And this value would be used in the second step to define the warm up length.

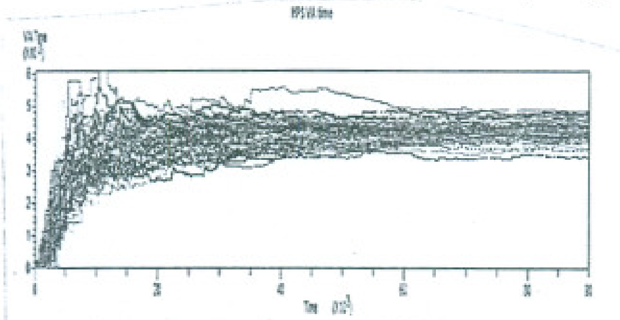

Figure 7, Graph of 50 replications with no warm up for the total value added time.

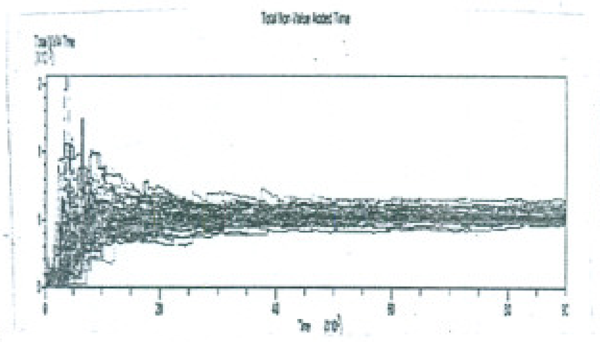

Figure 8, Graph of 50 replications with no warm up for the total non-value added time.

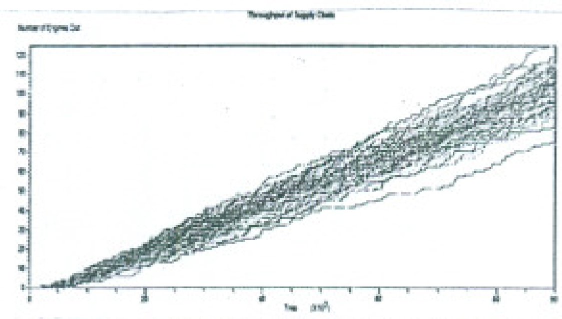

Figure 9, Graph of 50 replications w.th no warm up for the throughput of the supply chain.

If the simulation were taken to be a terminating model then these graphs would have acted as representatives of the model. The only difference would be that instead of time, quantity would be a driver. Warm up period would be there every time when the new order is placed. This would be very helpful to the companies, as it would tell how long it would take to remove the fluctuations in the supply chains and might pin point the problems, which would cause fluctuations. Author has assumed that the whole supply chain was based upon timely based contracts but in the supply chain customer may opt for a quantity based contract with some new supplier which would make the total supply chain a combination of timely and quantity based contracts. It may cause a lot of problems for doing the output analysis, as few portions in the supply chain would be of terminating type. Author suggests that performance measures of those terminating portions should be treated separately and the whole model's performance is treated as non-terminating type. It can be accomplished by first doing output analysis for the terminating type portions because when later, warm up would be defined, statistics for these terminating models would also be cleared. An analyst should be very careful while comparing alternatives in such combination of supply chain.

6.3.2 STEP 2

50 replications were made in this step but the warm up period was defined. The model was run for 90,000 hours. On reaching the 24,000 hours, which was the end of warm up period, all the statistics were cleared (see the figure 10 and 11) and Arena assigned new values to all the control values depending upon the model behaviour in the warm up period. Reader can see this in the figure 6-4 and 6-5 that statistic accumulator is cleared and there are extremely high fluctuations at that point. Initially, the steady state was reached at 24,000 hours but after clearing the accumulator and reassigning the control values the steady state was reached with in 15,000 hours i.e. 40,000 hours model run time. The results for the run were higher than the step one run because the model didn't start empty and idle. These results are more accurate. The means for total value added time is 4345.13 hours with the half width of 128.49. The results are higher for the total value added and non-value added time and lower for the throughput (79 engines out) because of the reasons that the actual run was reduced to 66,000 hours as the statistic accumulator was cleared at 24,000 hours.

Time Persistent	Avg	Half Width	Mini. Avg.	Max. Avg.
HPS_NVAleadtime	532.43	20.68	385.68	729.91
HPS_VAleadtime	4345.13	128.49	3573.98	5696.50

Table 3, Total value added and non-value added time results for the 50 replication run with the warm up period.

Number Out	Avg	Half Width	Mini. Avg.	Max. Avg.
Transportation to the Customer	79	2.77	60.00	103.00

Table 4, Throughput results for the 50 replication run with the warm up period.

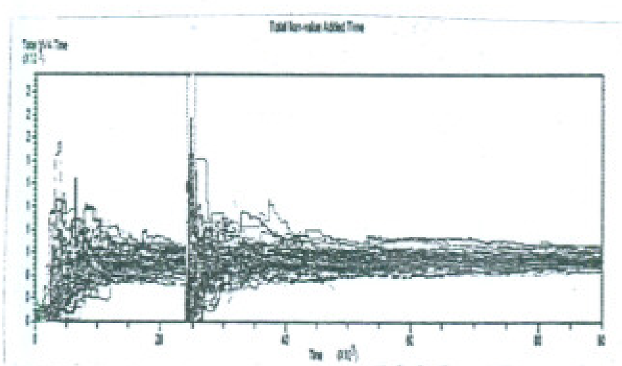

Figure 10, Graph of 50 replications with warm up period for the total value added time.

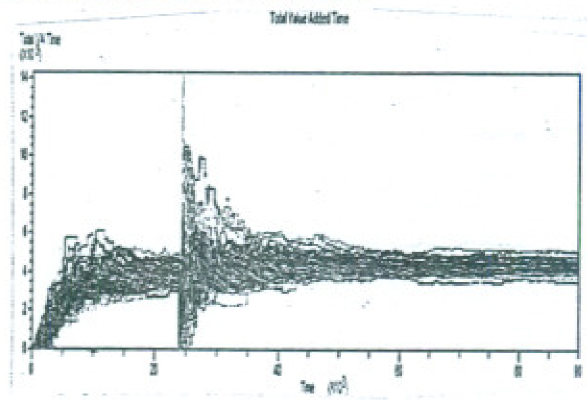

Figure 11, Graph of 50 replications with Warm up period for the total non-value added time.

Removing the warm up period totally might not be possible. All the methods minimise the effect of warm up on the over all results. Warm up period represents reality, as all the real world systems take some time to reach the steady state. Simulation here can help to locate those variables which cause lengthy warm ups and would suggest how to modify the real system to reduce the warm up length. Reader must have noticed when statistics accumulator was cleared and control values were reassigned, there were extremely high fluctuation. Similar high fluctuation normally occur in reality when either other operations are mixed with the original system, which normally occur in industry as new operation are always added up and they disturb the steady state or the system stops for any reason and starts over, may be because some break down or for any maintenance purpose.

VALIDATION

Validation is the process of determining whether the simulation model is an accurate representation of the real system? Hunting the answer to this question is cumbersome, as an absolute validity is almost next to impossible because a lot of assumptions might be used to build the model. Therefore, the analyst has to define a preferable degree of validity keeping in view of the assumptions he or she made while constructing the model. Even in defining this degree of validity, the analyst should valid the model from the point of view of his/her client, as every one has its own perception of reality [4]. One of the main hurdles in validation is related to the system data. Collecting system data is not an easy task and special attention should be given to the collection method to avoid the unnecessary data. This will also help to grow closer to the actual system. The proper validation won't be carried out firstly if the data is not available (which is the case here), secondly if available but insufficient, thirdly if the data is corrupted and lastly if the system doesn't exist. From the context of simulation, three different sets of data are required. First is the entities arrival time, as correspondingly entities would be created in the simulation. Second set is the sub-assemblies processing times, which would help to validate the processing times used in the simulation. And the last is the transportation times, which would validate the transportations times in the simulation.

One of the most important concerns here is the question of reliability. How reliable are the times, which are provided by the suppliers? The supplier will always be optimistic about its performance. The customer should rather do research of the supplier's history performance. This might not be a problem as most of the companies are ISO certified and keep a complete record of their activities. The suppliers who take the business seriously won't find any problem in sharing their records with their customers. Other than this, customer can define an optimistic[4] time (O), a pessimistic[5] time (P) and a most probably[6] time (M). Though, these terms belong to PERT analysis in the project management but the customer can make use of them in this regard to calculate the expected time (E). Following formulae are used to calculate the expected time and expected variance (VAR) and these formulae are based upon statistical estimation, probability distributions and Beta distribution.

$$E = (O + 4M + P)/6 \text{ and,}$$

$$VAR = ((P - O)/6)^2$$

These times will allow the proper risk assessment of the supplier's time. And this would lead to more reliable results.

When the sufficient observations from the real system are available, then different procedures can be used to compare it with the simulation output to determine whether the

[4] Optimistic time, in which the activity would be completed under the ideal conditions.
[5] Pessimistic time, in which the activity would be completed under the unfavourable conditions.
[6] Most probable time, in which the activity would be completed under the normal conditions.

model is an accurate representation of the real-world system [5] or not. Any of the following techniques can be used for the data validation;

- Inspection Method
- Confidence-Interval Approach Based on Independent Data, and
- Time-Series Approach [5].

Here only the names of the methods are mentioned, the reader can go through these methods in any of the simulation validation books. For readers help, see reference [5] more comprehensive detail on these methods.

The validation for the supply chain simulation model is a very sensitive topic, and especially for the supply chains in the extended Enterprise where the supply chain might be extended over the international borders and also involves two different companies at every supplier-customer junction. This arises many intangible issues like two companies have a total different way of operating, social issues, environmental issue, political issues, economical issues, people working attitude etc. Such issues might not be in the eye of analyst, because the analyst normally validates the model just for the system's tangible side e.g. input and output. Stressing here on intangible factors doesn't mean that the model validation concentrates more on these issues than the system's output, but these issues should be considered as a part of real system. It normally happens that the supplier, which suited best the customer and was providing desirable quality at the lowest rate was no longer opted for just because of its country's political situation or vice versa. Therefore, it will make the model credible[7] but not to be used because of the political or economic reasons [5].

The author has only considered the general aspects of simulation model validation, as the specific validation techniques cannot be applied because of the unavailability of actual system. The reader can go through such techniques in any of the management science simulation books; few are mentioned in the references.

6. Cost Analysis

The cost is one of the main performance objectives. And it was desired to see how the changes in the supply chain would affect the cost structure and would help to optimise and serve as decision-making criterion. For that purpose a simple cost model was built for cost analysis on Ms Excel. All the cost parameters were covered through value added costs and non-value added costs. Value added cost mainly covered the processing cost and material cost, whereas the non-value added cost covered the procurement cost and transportation cost. Other cost factors like holding cost, waiting cost, VAT etc were also covered through the two cost factors defined.

High Pressure Compressor Casing			
Entity Name	HPCasing	Process Value Added Time	12
Initial Value Added Cost	3	Transportation Non-Value Added Time	6
Initial Non-Value Added Cost	1	Process VA Cost per hour	2
Profit Margin	0.2	Transportation Non-VA Cost per hour	0.5
Process Value Added Cost	24	Total Number of Entities Out	5
Transportation Cost	3	Total Cost Including Profit	[illegible]
Total Entity Cost	31	Total Net Profit	[illegible]
Selling Price	37.2		
Profit	6.2		

Figure 12, Excel calculation sample cells for the cost model.

[7] Model credibility means that if the client and other key project personnel accept the model results [5]. A credible model is not necessarily a valid model or vice versa.

7. Comparing the Two Alternatives

The sole purpose of this simulation was to compare alternatives. Therefore, it was employed to make comparison between the in-house operation and the outsourcing. For both the cases, total hypothetical data was used. However, this data may be miles away from the real system data but still it provides good basis to make the comparison. These two alternatives covered the extreme, where either Rolls Royce is self-sufficient or Rolls Royce buys every thing from the other suppliers. Other than these Rolls Royce may have big list of alternative options where it buys few of the components or sub-assemblies from different suppliers or it check the performance of two suppliers for a single component or sub-assembly supply.

The basic comparison between the two options would include:

- Lead time for the supply chain to make single unit,
- Throughput of the supply chain, and
- Cost analysis for the supply chain.

However, equal emphasis would be laid on all the criteria but the stress would be more on cost analysis, as cost would be the major decision criterion. For both alternatives, a set of 50 replications would be run to attain results that are more precise.

7.1. Lead Time Comparison

Lead-time for the two alternatives was almost the same. The difference between the lead times was only 10 hours. Even in the outsourcing model, the components spent more time on non-value adding activities that was transportation than value adding activities (see the table 5). This lead-time could be reduced further if more concentration is put on the non-value adding activities. Value stream mapping could be used for this purpose. Nevertheless, the debate on control and core competencies would remain. As if the Rolls Royce goes for outsourcing, then it could concentrate more on its core competencies but will lose control over the activities because it would be depending on other companies. And opposite is the case if Rolls Royce opts for in-house operations, because it would provide them total control but would unable to polish their core competencies.

Outsourcing here is an extreme case, but it tells how much time the Rolls Royce could save if it makes contracts with the companies, which are in second or third world countries. As their processing times and quality are as good as Rolls Royce's and because of fast means of transport and the advanced logistics management the total lead time can highly be reduced. But in such an outsourcing case lead-time would be subjected more to vulnerability because of the multiple authorities would be involved but the Rolls Royce could outsource those sub-assemblies which are not that important e.g. Low Pressure compressor Front Casing, Low Pressure Compressor Rear Casing, Low Pressure Rotor etc, which lies on the non-critical path. If for any reason these orders are delayed, it won't affect the lead-time. Other benefit would be Rolls Royce would concentrate more on its core competencies.

Lead Time	Alternative type	Value	Throughput
Value added time	In-house	4274.82	40
Non-value added time	In-house	323.39	
Value added time	Out-sourcing	4071.77	59
Non-value added time	Out-sourcing	535.92	

Table 5, lead time and throughput comparison between the two alternatives

7.2. THROUGHPUT

Throughput results are better for the outsourcing even though lead-time for the outsourcing run was a bit more than in-house run. The author thinks of two reasons for the better output of outsourcing:

- An in house operation has multi-level material procurement, which affect the throughput. Rolls Royce has to maintain multi-level inventories and there would be more material flow in the manufacturing plants from one station to another. The sub-assemblies would have to wait more because the presence of other products.

- The steady state in the outsourcing model was achieved earlier with less fluctuation, which caused more units out. The throughput was increased further in the modified run outsourcing run when warm up period was changed from 24,000 hours to 18,000 hours. It was almost 50% increase to throughput of in-house run (i.e. from 40 units to 59 units).

The throughput would be improved if Rolls Royce outsource few of the sub-assemblies because it would cause less material procurement at different level and consequently, material management would be reduced. Roll Royce could use these resources to focus more on the other activities.

7.3. COST COMPARISON

Total cost of the engine in the outsourcing model is less than that of the engine produced in-house. Mainly, it is because of suppliers had less processing cost because of the cheap labour available in the other countries, which made them offer better prices. It was an extreme case as every thing was outsourced and other than that all the values were hypothetical, but still supplier in such countries would be able to throw better prices. Price comparison was made between the costs of sub-assemblies for the two alternatives (see the figure 13). The difference between the costs of each sub-assembly does not seem that much but the accumulated cost difference for the final product is a lot. Engine, which was made in house, cost 753,588.2 pounds and outsource for the engine was 670,377 pounds. It makes the difference of 83,221.2 pounds, which is a lot for a single engine. Outsourcing of High Pressure System would be more expensive; therefore, it should be made in-house. Rolls Royce could outsource sub-assemblies High Speed Gearbox, Intermediate Casing and Low Pressure Rotor and few of the sub-sub assemblies. This would increase its profit margin as suppliers are providing them cheap. Though, other sub-assemblies, especially High Pressure Turbine, High Pressure Compressor, Intermediate Pressure Turbine and Compressor etc, cost more too but should not be totally sourced, because making them in-house would provide more control over the total product.

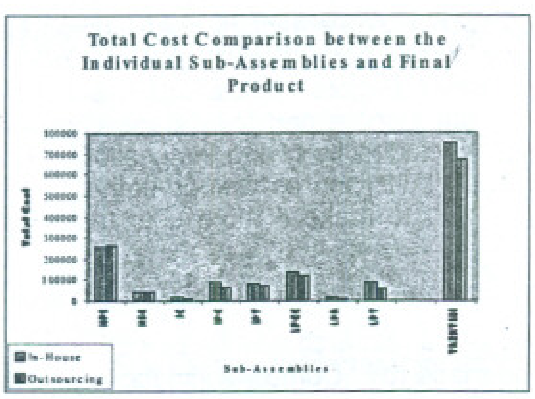

Figure 13. Cost Comparison between sub-assemblies for in-house and outsourcing.

In the figure 14 and 15, a comparison between the total value added cost and total non-value added cost for each sub-assembly for both the run has been made. It would help the Rolls Royce to compare their value adding activities with the suppliers. It would help to decide more precisely about the individual outsourcing of components. And also if not outsourcing it would help to locate where Rolls Royce is spending more and what strategies it could make to reduce the cost. As for non-value added cost graph, it could help it in value stream mapping or any other technique which might be used to reduce the cost of non-value adding activities.

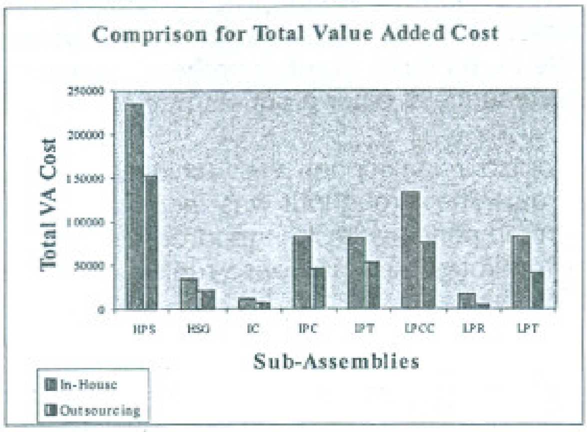

Figure 14. Total value added cost comparison between the in-house and the outsourcing.

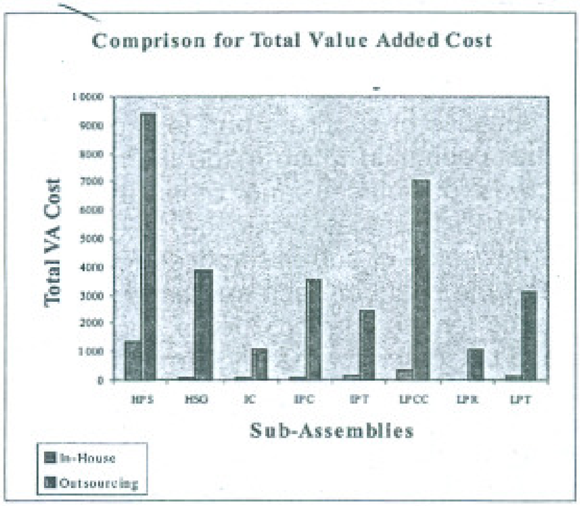

Figure 15. Total non-value added cost comparison between the in-house and the outsourcing.

8. Conclusions

Simulation is now used in every professional sector. Different software is available to fulfil the needs. The reason of such achievement is cheap computer technology. However, simulations benefits for the supply chain were sought quite late, but still a lot of progress has been made in the sector. As in other sectors, simulations has not only helped to make the present problems prominent and but also helped to see the effects and working of different proposal in reality. The paper is concluded by giving suggestions to cover better utilisation of simulation to attain more accurate results and as well as some words on future prospects of simulation; how it could be managed to make it more user friendly and support better data management.

8.1 Better Utilisation

The simulation developed in the research worked properly under the assumptions made, but many improvements could be made to it. Complete simulation of the real system may not be possible, but it should have enough details of the real system so that the decision can be made, based on simulation output. The section describes what can be added to the simulation to make its results more reliable.

8.2. Variable Processing Times

A single mean value was defined for the processing time, which depicted the regular production. But whenever a new order is placed, a new tooling would be required to fulfil the order. Therefore, the first product always takes more time then rest of the follow on products. This causes a variable processing timing. Modifying the model to accommodate such variable processing times would make the simulation results more reliable and would bring the simulation closer to the actual system

8.3. Data Risk Analysis

The output of the simulation totally depends on the accuracy of the input data. Here the data was very hypothetical but the suppliers would mostly quote data for the real system and they are always optimistic about their performance. The customer company has to do proper data analysis before they use it in the simulation. They could define a performance range in which the supplier's performance normally lies. Same technique as used in the PERT Analysis could be employed to calculate the expected supplier lead-time and its throughput. Based upon the supplier performance history, an optimistic, a pessimistic and a most probable value could be defined. All quality conscious companies are ISO certified, and maintain a complete record of their performance. They would gladly share their records with the customer company, as it would increase the chances to catch more business.

8.4. Optimization

The customer company has different options of supply chain structure for the particular product. They could outsource a single component, a portion of sub-assembly or a whole sub-assembly. In addition, for same component different suppliers could be an option. Each would have its own performance measures. In summing up, it would make a large number of alternatives just for a single sub-assembly. If the product is complex like Trent-800 engine, then finding the optimum, solution even using simulation, would be very difficult. If the supply chain structure is already defined, there would still be a lot of constraints like processing capacity, transportation capacity, product mix, machine availability etc, would make a large number of alternatives. Analysing output of all the alternatives might not be possible. The best would be to short-list the important constraints and alternatives and then compare the output of these alternatives to obtain the possible best solution.

8.5. Linking with the Database Servers

A key idea presented in this simulation development, is that data would come directly from a common database of product and supplier data. In the future, Extended Enterprise will provide an Internet based database where different suppliers can come and quote their capabilities, prices and their performance measures. So, linking of such database would be of great help, as data would directly come to the simulation model the customer company just could run the model and go through the results, whether working with that supplier would be compatible or not?

Most of the companies are ISO certified and they keep an internal database about their own performance measures. Linking simulation with such database would allow the companies to benchmark their performance with other companies. It could help to locate non-value adding activities in their supply chains, and, help them to build strategies to become better than their competitors.

Such database based simulation would help a lot to the companies which either make complex products, like Rolls Royce or which make fast moving consumer goods like mobiles, computers etc. because lead time is the most important issue there.

8.6. Dynamic Simulations

Companies always have more than one supply chain and constructing a separate simulation for each supply chain might not be possible. Other than this, even for a single supply chain there are many possible structures. A supplier can offer a component as well as a whole assembly. This could entirely change the supply chain structure. Modifying simulation to accommodate such changes would be a difficult job. What if simulation dynamically creates a new required supply chain structure based on database structure? This sounds a very difficult job, but achieving such simulation would be great. One does not have to worry about the changes in supply chain structure.

8.7. Post Analysis Suggestion

Supply chain could be considered as a set of dependent activities, therefore project management techniques like CPM and PERT could be utilised for the post simulation analysis. If simulation output result could be directly exported to such analysis software, then it would help to calculate the slack time related at each level. It would help to locate the probability of non-critical paths to become a critical path. This would further help to calculate the optimum order placement time as well the optimum order quantity. It would optimise the supply chain.

8.8. Extending the Simulation to the Downstream Activities

This project only covered the upstream activities i.e. the procurement side, but this simulation could be extended to the downstream activities i.e. distribution side. It would become a complete tool, which could help to analyse the whole value stream. Simulating the downstream would not be difficult because the downstream make the mirror image of upstream activities.

Simulation-started off as independent technology, but the software companies realised that the true benefit of simulation could only be obtained if it is integrated with other technologies. However, the new simulator are very flexible, but still they still lack user friendly data import and data export tools, that makes the communication with other technologies very rigid. Linking simulation with the database is very crucial as it will centralise the whole system and reduce data redundancy. Consequently, it would give better data management and would speed up the decision-making time.

This project was a first step towards flexible simulation. It presented an idea, which is still in the raw form. More research would be required to polish the idea. The author has suggested ideas, which would help to make it more useful. Professional projects based upon the idea would increase the industrial interest. Such flexible simulations are the true tools, which can easily fulfil the dynamic requirements of the Extended Enterprise. Companies in the Extended Enterprise cannot tolerate waiting for decisions because of customer and supplier uncertainty. Furthermore, due to the stringent competition the decision making time has been reduced. Therefore, such simulation would help to achieve quick decisions. To sum up all, flexible supply chain simulation is the need of the hour!

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SIM-UTILITY : MODEL FOR PROJECT CEILING PRICE DETERMINATION

By

Wel-Chih Wang*

Abstract :

Before considering bids submitted by competing contractors for a public procurement project, the owner should determine a project ceiling price or cost estimate to use as a reference point for evaluating the bids. A high ceiling price conflicts with the owner's interests in minimizing costs. Meanwhile, a low ceiling price can jeopardize the project if all bids exceed the ceiling price. This paper proposes a model for determining a reasonable project ceiling price. The model, called SIM-UTILITY, is based on a utility theory and facilitated by a cost simulation approach. The utility theory is applied to reflect the owner's preferences regarding the determination criteria, while the simulation approach is used to generate more objective project cost data to support execution of the utility theory. The advantages of SIM-UTILITY are proven by its successful application to three construction projects in Taiwan.

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CE Database keywords : Project management ; Cost estimates ; Bids ; pricing ; utility theory.

Introduction

Before allowing bidding to open among competing contractors for a public procurement project, the owner should determine a project ceiling price or cost estimate to use as a threshold or reference point for accepting or rejecting bids (GPL 1999). A high ceiling price conflicts with the owner's interest in minimizing costs since it potentially allows the successful bidder to earn excessive profit. When the difference between the price and most bids is large, a high ceiling price may also imply that the owner or a retained architect / engineer (A / E) has not estimated the costs accurately (i.e., the price does not reflect market conditions). However, a high ceiling price eases the process of tendering out the project because it becomes easier to find a bid that is lower than the price.

On the other hand, a low ceiling price creates a risk that all bids will be rejected and the project withdrawn for redesign or reconsideration, since all bids may exceed the ceiling price. Beginning project tendering afresh is time-consuming and increases the owner's liability for potential delays in the project completion date. The low ceiling price may also pressure bidders to make unrealistically low bids, meaning that the winner may then cut corners during construction to increase its operating margins. Despite these disadvantages, however, a low price is politically desirable because it indicates that the project owner is conscious of saving taxpayers' money.

The dilemma for the project owner is to set a ceiling price that is sufficiently low to satisfy the owner's interests in cost saving, yet sufficiently high to successfully tender out the project. In Taiwan, the ceiling price for a public project is determined based on a cost estimate prepared by

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the A / E. This cost estimate is then treated as the project budget. While some owners fix a ceiling price by multiplying the A / E's cost estimate by the average bidding ratio (winning bid divided by ceiling price) of past projects (frequently an unjustified bidding ratio becomes a multiplier of the A / E's cost estimate), most owners merely make a decision based on gut feeling. Despite its popularity, the historical average bidding ratio is inferior to more systematic evaluation methods. The major problem is that the ratio tends to be unrealistically low, especially in a slow construction economy when bidders tend to propose unsustainably low bids simply to get a contract. A further drawback is that the unique characteristics of the project are ignored.

The lack of a systematic evaluation model to help determine project ceiling prices has weakened confidence in pricing decisions among the owners of public construction projects in Taiwan. Project owners are constantly concerned by accusations of incapability or corruption. A model for fixing project ceiling prices would provide project owners with strong evidence to serve as an easily justifiable basis for their professional decisions, regardless of how the tendering results.

Current research has focused either on the development of bidding models to assist bidders in winning contracts (Carr 1987 ; Ioannou 1988 ; Moselhi et al, 1993 ; Dozzi et al, 1996 ; Fayek 1998) or on the evaluation of competitive bids (Crowley and Hancher 1995 ; Crowley 1997). To the writer's knowledge, no previous work has investigated the problem of dertermining the project ceiling price.

This study proposes a model, called SIM-UTILITY, that is built on a utility theory and facilitated by a cost-simulation approach The utility theory is applied to find the preferences of the decision-makers in determining the ceiling price. Meanwhile. the simulation approach is employed to increase the objectivity of the project cost data and thus support the execution of the utility theory. The proposed model has been successfully applied to three real construction projects in Taiwan. The proposed model is described below, and its detailed workings are demonstrated using one of the application projects. Finally, the results of all three application projects are presented, discussed, and validated.

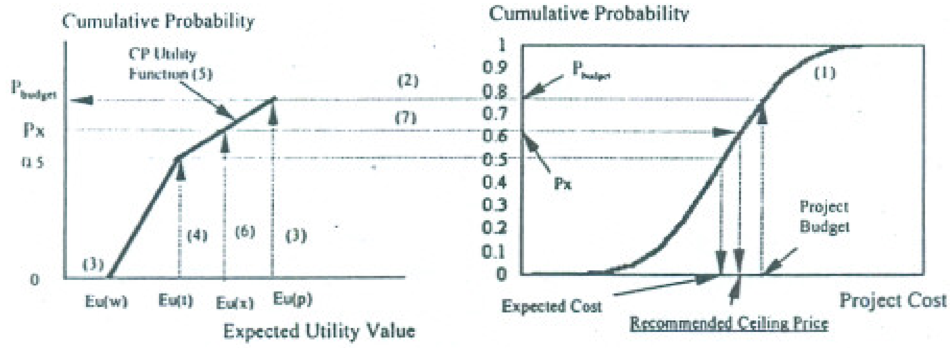

Fig. 1. Modeling procedure of SIM-UTILITY

Proposed Model

The key to developing SIM-UTILITY is first to identify various criteria that the owner will consider in discounting the A / E's cost estimate to come up with a ceiling price. Next, provided the upper and lower boundaries of the project ceiling price are found with respect to a best and worst-case evaluation of these criteria, a recommended ceiling price should be obtained with respect to particular evaluation results. While the criteria are evaluated using the utility theory, the boundaries of the project ceiling price are identified simulation.

Fig. 1 illustrates the detail modeling procedure of SIM-UTILITY. The left of the figure presents an expected utility function generated based on the user's preferences regarding the identified criteria, while the right part displays a cumulative probability distribution of the simulated project cost. The procedure consists of the following seven steps ;

1. Perform simulation analysis and then generate a cumulative probability distribution of project cost.

2. According to the distribution, find a cumulative probability with respect to the project budget (namely, the upper boundary of the project ceiling price), P_{budget}.

3. If high values or scores are assigned to favorable criteria evaluations, this probability, P_{budget}, can be considered the highest probability with respect to the user's highest utility value, Eu (p). Meanwhile, a probability of 0, which is correspondent with the minimum project cost (i.e., lower boundary), has a minimum utility value, Eu (w), at which the evaluation result will be least favorable. Both Eu (p) and Eu (w) are obtained through a series of evaluation steps of utility theory.

4. Set the probability of the expected utility value for the threshold points of criteria, Eu(t), at 0.5 or 50% (the threshold point for each criterion represents the point of neutral desirability). This value implies that the owner wishes the winning bidder to have a 50 / 50 chance of over-run or under-run when completing the project under the threshold conditions. The 50/50 probability implies that the ceiling price will closely approximate the expected project cost. Notably, however. SIM-UTILITY allows the flexibility to choose a different value of probability with respect to Eu (t).

5. Assuming a linear relationship, develop the ceiling price (CP) utility function based on the three points identified [Eu (w), 0], [Eu (t), 0.5], and [Eu (p), P_{budget}]. Other relationships can be used for describing the CP utility function based on the owner's perception of how the probability may vary for a change of utility function, as long as such a relationship can be defined. Examples of potential candidate relationships include exponential, or s-curve like (e. g., combining with concave and convex) curves. Our use of a linear relationship herein represents the perception of CP utility function for the owner of the application projects.

6. After evaluating the utility value of each criterion of the project, compute the expected utility value of project x, Eu (x). According to the straight-line utility functions developed above, find a probability, Px, with respect to Eu(x).

7. Based on the value of Px, find a recommended ceiling price based on the cumulative distribution of the project cost.

In SIM-UTILITY, the procedure of applying utility theory resembles that developed by Dozzi et al. (1996). The similarities include identifying the criteria for determining the ceiling price, specifying the range of scale (namely, lower limit, threshold point, most preferred point, and upper limit) for each criterion, developing a straight-line utility function for each criterion, weighting the relative importance of each criterion over pair-wise-compared criteria, producing a common-scale utility for each criterion, and establishing the straight-line ceiling-price utility function.

Instead of directly obtaining the value of the ceiling price, a normalized or dimensionless value of measure (that is, probability) between 0 and 1 is first derived. This normalization approach is practical since it resembles the markup decision process, in which the markup is decided in percentage rather than in absolute terms. Another benefit of this normalization approach is that the probability value reveals practical implications. That is, the value of probability for a particular ceiling price can be interpreted as "the maximum chance that the owner is wiling to give the bidders of not losing money at such a ceiling price." Similarly, after awarding the contract to a bidder, the value of probability with respect to the bid can be used to represent the chance of the bidder completing the project profitably. Assume that the higher the chance of making a profit, the higher the project quality will be (that is, the contractor will have more money to spend on quality control). If a bid with a low probability emerges as the winner, SIM-UTILITY gives the owner an early warning to pay particular attention to quality control because the contractor may use devious means to minimize possible losses. Accordingly, it is unwise to fix a ceiling price with a probability of 0, since it will leave the winning bidder with no chance of making a profit.

The simulation approach is a feasible means of implementing the above normalization approach and supports execution of the utility theory. As shown in Fig. 1, the simulation approach provides a cumulative probability of between 0 and 1, and its simulated distribution of project cost can be used to identify the project cost (that is, recommended ceiling price) given a particular probability value.

Application to Practical Project

The SIM-UTILITY model has been applied to three subprojects (architectural, electrical, and mechanical) of a recent construction project, the Civil Service Development Institute (CSDI) project. Using the architectural project as an example, this section illustrates the detailed algorithms of both simulation approach and utility theory for SIM-UTILITY and presents the application results.

Project Description

The CSDI project is located in central Taipei, Taiwan. Besides three underground floors, the project includes a 14-story hotel-like dormitory, a 6-story educational building, a 6-story building containing an 800-seat capacity meeting hall, and a 200-person capacity convention hall, and a 3-story office building. The project uses a mixture of reinforced concrete and steel structures. The total budget of the project is approximately U.S. $ 42.6 million, and the budget of the architectural portion is approximately U.S $ 30,166,667 (905,000,000/30) (1 U.S dollar ≅ 30 New Taiwan dollars). To meet the objective of completion by mid-2000, the project is being fast-tracked. The project team includes an owner, a construction management group, an A\E, a prime contractor (architectural), seven contractors (including electrical, mechanical, and others), and several subcontractors.

Cost Simulation approach

In a probabilistic estimation of project cost, each cost component is represented by a suitable statistical distribution (Touran and Wiser 1992). The total project cost, displayed in Eq. (1), is thus a random variable that is the sum of several random numbers:

$$C_{Tot} = \sum_{j\,1}^{n} C_j$$

In which C_{Tot} denotes the total project cost. C_j represents cost component j, and n is the number of cost components.

In the simulation-relevant algorithms of SIM-UTILITY, three point estimates (optimistic cost, mode, and pessimistic cost) are used to produce a beta statistical distribution of each cost component .The three-point estimate approach is attractive because it is familiar to most construction practitioners, being widely applied in probabilistic network-based scheduling (for example, in the program evaluation and review technique). However, other methods (such as the direct assignment of a particular distribution to a cost component) can also be used, provided the cumulative distribution of project cost can be generated.

As suggested by Touran and wiser (1992), it is impractical to consider every single variable that goes into a detailed estimate. Thus the cost items considered are those that appear on the estimate summary sheets of the project, namely the C_js in SIM-UTILITY. While most C_js are measured in dollar terms, some are expressed in percentage terms because of their supportive or indirect characteristics. For example, the cost of installing temporary water and electricity supplies, treating construction wastes and environmental pollution, and paying construction insurance are conventionally estimated as percentages of the total direct costs of the project (such as excavation, structure, finishes, doors, windows, painting, and furnishing). Furthermore, by focusing only on the costs required to complete the project, the project cost C_{Tot} excludes profits or markups. Thus the probability value given a particular project cost indicates the probility of the contractor not losing money at that cost.

Table 1. Three point Estimates for Each Cost Component (in U. S. Dollars)

Cost component	Optimistic cost	Most likely cost	Pessimistic cost
1. Excavation	5,033,519	5,210,134	6,887,974
2. Structure	9,885,523	10,232,384	13,527,558
3. Finishes	4,074,271	4,217,228	5,575,318
4. Doors, windows, glass	3,054,753	3,161,937	4,180,188
5. Miscellanies	2,089,097	2,162,399	2,858,765
6. Furniture	45,086	46,668	61,697
7. Planting	152,255	157,598	208,349
8. Kitchen equipment	194,452	201,275	266,093
9. Swimming pool	287,193	297,270	393,001
10. Shop drawing composition	152,950	158,317	209.300
	Optimistic (%)	Most likely (%)	Pessimistic (%)
11. Temporary water and electricity	0.285	0.295	0.39
12. Temporary dewatering	0.475	0.492	0.65
13. Temporary power systems	0.095	0.098	0.13
14. Waste, pollution management	0.285	0.295	0.39
15. Site safety management	0.095	0.098	0.13
16. Quality control	0.475	0.492	0.65
17. Temporary facilities	0.475	0.492	0.65
18. Construction insurance	0.114	0.118	0.156
19. Tax	5	5	5

Since the execution of SIM-UTILITY does not rely on precisely computing C_{Tot}, and since solving Eq. (1) can be time-consuming, a simulation approach is adopted herein. Simulation involves a procedure for generating random costs according to C_i distributions that then sums these costs to obtain the total project cost. This procedure

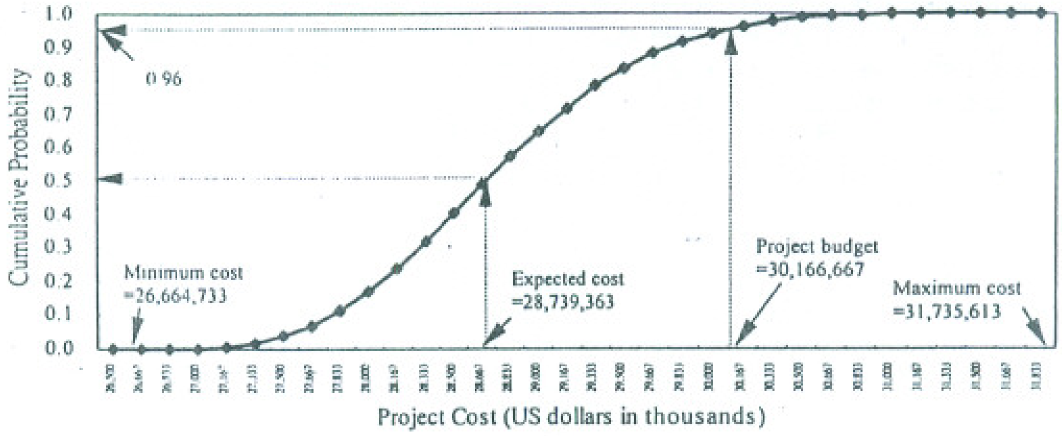

Fig. 2. Cumulative probability distribution of project cost

is repeated several hundred times, with C_{Tot} being computed each time. A cumulative probability distribution of total project cost can then be constructed from the values of C_{Tot}. This distribution is used to estimate the probability of completing a project at or below a particular cost.

A newly developed simulation language, STROBOSCOPE (Martinez 1996), is used to execute the simulation-relevant procedure described in SIM-UTILITY. This procedure, based on STROBOSCOPE, was implemented on a 586 PC with 64 Megs of RAM under a 32-bit Windows environment (namely, Windows 97). Analyzing 21 cost components of the application project 10,000 times took approximately 45 min. The run time should be significantly reduced by using faster PCs and refining the source code of the model.

Table 2. Definitions, Range of Scales and Utility Functions of Criteria

Criterion i	Description of Utility	Range (y_L, y_U)	y_T	y_M	A_i	B_i
1. Environment						
1.1 Estimator's accuracy	High accuracy of estimate → high ceiling price (title need to further discount A /E's estimate)	(0, 100); high=100; Low=0	30	100	0.0143	−0.4286
1.2 Historical bidding ratio	High bidding ratio → high ceiling price	(0.3, 1.0) ; average bidding ratio	0.6	1	2.5	−1.5
1.3 Market condition	Good construction economy → bidders have more opportunities → loser can still seek other opportunities → high ceiling price for more likely tendering out of the project	(0, 100) ; good =100 ; poor=0	30	100	0.0143	−0.4286
2. Qwner						
2.1 Tendering urgency	High urgency → high ceiling price for more likely tendering out of the project	(0, 100); high=100; low=0	30	100	0.0143	−0.4286
2.2 Budget tightness	Project budget is tight → high ceiling price for more likely tendering out of the project	(0, 100);tight=100; loose=0	50	100	0.02	−1
2.3 Avoiding controversy	High bidding ratio → being easily accused of poor estimation → low ceiling price	(0, 100); low=100; high=0	50	100	0.2	−1

3. Project						
3.1 Bidder's qualifications	High qualification → better bidders → low possibility of unrealistically low bids → high ceiling price	(0, 100); high=100; low=0	50	100	0.02	−1
3.2 Project duration	Tight duration → high risk → high bidding price → high ceiling price for contractor to meet project deadline	(0, 100); tight=100; loose=0	30	100	0.0143	−0.4286
3.3 Project complexity	High complexity of project → high risk → high bidding price → high ceiling price for contractor to meet specifications	(0, 100); high=100; low=0	30	100	0.0143	−0.4286

Note : y_L = lower limit ; y_U = upper limit ; y_T = threshold point ; y_M = most preferred point ; and A_i , B_i = constant of $U(y_i) = A_i xy + B_i$.

Simulation Inputs

For this application project, the specific statistical distribution for each cost component was derived from the values of the three point cost estimates by assuming a bèta distribution with shape parameters α and β . Table 1 presents these simulation inputs.

Simulation Outputs

The simulation analysis found that the minimum, expect, and maximum cost of the application project are U.S. $ 26,664,733,U.S. $ 28,739,363, and U.S. $ 31,735,613 with respect to the cumulative probabilities of 0, 0.49, and 1, respectively. Fig. 2 displays the generated cumulative probability distribution of the total project cost. (During the construction phase, the results illustrated in Fig. 2 were presented to the jobsite superintendent and were considered reasonable). By interpolating the distribution the probability of successfully completing the project within budget (U.S. $ 30,166,667), P_{budget}, equals 0.96.

Table 3. Preferences of 1st-Level Criteria

Criteria	1. Environment factors	2. Owner factors	3. Project factors
1. Environment factor	1	1/7	1/5
2. Owner factors	7	1	1/3
3. Project factors	5	3	1

Utility Theory

The application of utility theory requires that each criterion influencing the ceiling price be defined and represented by a utility function. Pair-wise and hierarchical comparison of the importance of each criterion allows a weighting factor to be assigned to each one. The weight is further adjusted for the classification within the hierarchical structure. Multiplying the utility value by a corresponding adjusted weight obtains a common scale utility value for each criterion. The sum of all common scale utility values is the expected utility value for a particular project scenario.

Identification of Determination Criteria

The nine major criteria considered in determining the ceiling price were identified through interviews with two senior Taiwanese government officials with experience in this area. These criteria can be divided into three 1st-level categories, namely environment-related factors, owner-related factors, and project-related factors. Each of these three 1st-level criteria is then further divided into three 2nd-level criteria, which are described below and summarized at the left of Table 2.

The environment-related factors include the accuracy of the A/E's estimate, the historical bidding ratio, and market conditions. For most public building projects, A/E's normally neglect their estimates to focus on their designing job. This environment of poor estimation has markedly influenced ceiling-price judgments in Taiwan. Since the A/E's fee is related to project cost, the A/E's estimate tends to be too high, and the owner generally discounts it. Additionally, despite the unique characteristics for each construction project, the historical bidding ratio of similar past projects may be used as a reference for the current project. Regarding market conditions, most practitioners agree that bidders tend to offer low bids during a slow market to keep their business running, and tend to bid high to compensate for their losses when the economy improves. Thus, the ceiling price should respond to market conditions, being lower when the economy is slow, and vice versa.

Project owners in Taiwan must consider the criteria of tendering urgency, budget tightness, and avoiding controversy. Since most public construction projects must be completed rapidly to demonstrate government efficiency, owners are eager to tender the projects out as soon as possible. A higher ceiling price is more likely to achieve tendering rapidly. Most public projects in Taiwan have a budget that is insufficient to

Table 4. Preferences of 2nd-Level Environment-Related Criteria

Criteria	1.1 Estimator's accuracy	1.2 Historical bidding ratio	1.3 Market conditions
1.1 Estimator's accuracy	1	7	9
1.2 Historical bidding ratio	1/7	1	3
1.3 Market condition	1/9	1/3	1

meet the desired project needs. The tight budget motivates the owner to set a higher ceiling price (that is, not to discount the A/E's cost estimate) to maximize the chance of finding a bid that falls below the price. However the higher ceiling price encourages a lower bidding ratio (winning bid/higher ceiling price), which can lead to the owners being accused of either producing a substandard estimate or squandering public money. Thus it is also important to prevent the ceiling price from becoming too high.

Table 5. Preferences of 2nd-Level Owner-Related Criteria

Criteria	2.1 Tendering urgency	2.2 Budget tightness	2.3 Avoiding controversy
2.1 Tendering urgency	1	5	9
2.2 Budget tightness	1/5	1	3
2.3 Avoiding controversy	1/9	1/3	1

Project-related factors include the qualifications of competing bidders, project contract length, and project complexity. Most owners believe that highly qualified bidders submit reasonable bids and thus feel little pressure to discount the A/E's cost estimate. Meanwhile, projects with a shorter duration and higher complexity should have a higher ceiling price to provide bidders with a greater chance of obtaining a profit.

Utility Function of Individual Criteria

The utility functions for each criterion represent the owner's preferences over a range of options and are measured on a scale. Similar to the utility theory model proposed by Dozzi et al, (1996), the steps used to develop a utility function in SIM-UTILITY are summarized as follows :

1. Specify the upper limit (y_U) and lower limit (y_L) for each criterion i.

2. Identify the theshould point (y_T) and most preferred point (y_M) for each criterion i. The utilities of y_T and y_M are set at 0 and 1, respectively; that is, $u(y_T)=0$. and $u(y_M)=1$.

3. Use a straight-line function to express the utility function for each criterion i. That is, the utility value of a particular y_i can be obtained by

$$U(y_i) = A_i \times y_i + B_i \qquad (2)$$

Where A_i and B_i are constants.

Table 6. Preferences of 2nd-Level Project-Related Criteria

Criteria	3.1 Bidder's qualification	2.3 Project duration	3.3 Project complexity
3.1 Bidder's qualification	1	4	7
3.2 Project duration	1/4	1	3
3.3 Project complexity	1/7	1/3	1

Table 7. Weights and adjusted Weights for all Criteria

1st-Level criteria	2nd-Level criteria	$W_{i\,(1st\text{-}level)}$	$W_{i\,(2nd\text{-}level)}$	$S_i = W_{i\,(1st\text{-}level)} \times W_{i\,(2nd\text{-}level)}$
1. Environment		0.0746[a]		
	1.1		0.7854[b]	0.0586
	1.2		0.1488[b]	0.0111
	1.3		0.0658[b]	0.0049
2. Owner		0.3236[a]		
	2.1		0.7514[c]	0.2432
	2.2		0.1782[c]	0.0577
	2.3		0.0704[c]	0.0228
3. Project		0.6018[a]		
	3.1		0.7049[d]	0.4242
	3.2		0.2109[d]	0.1269
	3.3		0.0842[d]	0.0507

[a] maximum eigenvalue = 3.2332.

[b] maximum eigenvalue = 3.0803.

[c] maximum eigenvalue = 3.0291.

[d] maximum eigenvalue = 3.0324.

The sum of scales for each class or subclass equals 1.

4. Solve the constants A_i and B_i of each function for each criterion i.

By conducting the aforementioned steps, the values of y_U , y_L , y_T , y_M , A_i and B_i of the nine determination criteria for this application project can be obtained and are illustrated in the right part of Table 2. Note that the scale for each criterion is a numerical value.

Weightings of Determination Criteria

Each criterion is assigned a weight to distinguish the preferences among the preferences of criteria from the same classification level (namely, 1st or 2nd level) of the hierarchical structure. The sum of the weights for each classification level equals 1. The weight of each criterion i is denoted by W_i. The scale used to derive the relative importance from matrices of pair-wise comparisons ranges from 1 to 9 (Saaty 1978), as follows : 1 = equally important ; 3 = slightly more important ; 5 = strongly more important; 7 = demonstratedly more important ; 9 = absolutely more important ; 2, 4, 6 and 8 are values denoting a degree of importance lying between 1 and 3, 3 and 5, 5 and 7, and 7 and 9, respectively.

In this application project, the preferences of the 1st-level criteria (that is, environmental, owner, and project-related factors) are evaluated and listed in Table 3. The preferences of the 2nd-level criteria under each of the 1st-level criterion categories are evaluated and presented in Tables 4, 5 and 6 respectively.

Table 8. Expected Utility for Worst-Case Selections

Criterion	Criterion selection	interpreted scale (y)	A_i	B_i	$U(y_i)$	S_i	Common scale utility
1.1	Low	0	0.0143	−0.4286	−0.4286	0.0586	−0.0251
1.2	0.3	0.3	2.5	−1.5	−0.25	0.0111	−0.0083
1.3	Poor	0	0.0143	−0.4286	−0.4286	0.0049	−0.0021
2.1	Low	0	0.0143	−0.4286	−0.4286	0.2432	−0.1042
2.2	Loose	0	0.02	−1	−1	0.0577	−0.0577
2.3	High	0	0.02	−1	−1	0.0228	−0.0228
3.1	Low	0	0.02	−1	−1	0.4242	−0.4242
3.2	Loose	0	0.0143	−0.4286	−0.4286	0.1269	−0.0544
3.3	Low	0	0.0143	−0.4286	−0.4286	0.0507	−0.0217
							Total score = −0.7206

The matrix of preferences is manipulated via a method that determines the eigenvector corresponding to the maximum eigenvalue of a matrix. For example, the eigenvector for the matrix of Table 2 (preferences of 1st-level criteria) is (0.0746, 0.3236, 0.6018) using the maximum eigenvalue of 3.2332. That is, the weights for environment, owner, and project-

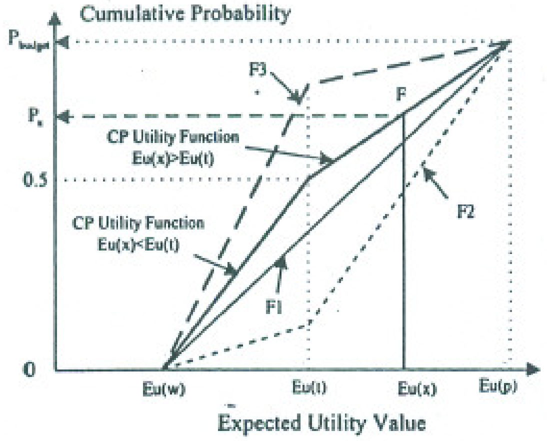

Fig. 3. Possible types of ceiling price utility function

related criteria are 0.0746, 0.3236 and 0.6018, respectively. These weights are then adjusted for classification within the hierarchical structure. The adjusted weight for criterion i is thus obtained by the following equation :

$$S_i = W_{i\,(1st\text{-}level)} \times W_{i\,(2nd\text{-}level)} \quad (3)$$

where $W_{i\,(1st\text{-}level)}$ denotes the weight of the 1st-level criterion i, and $W_{i\,(2nd\text{-}level)}$ represents the weight of the 2nd-level criterion i.

For the application project, the weights ($W_{i\,(1st\text{-}level)}$ and $W_{i\,(2nd\ level)}$) and adjusted weights (S_i) for all criteria are calculated and listed in Table 7. For example, in Table 7 the adjusted weight for the criterion of the estimate's accuracy is equal to 0.0586, which is obtained by multiplying 0.0746 by 0.7854. The sum of the adjusted weights of all criteria should equal 1 as a check to ensure there have been no errors in adjusting weights.

Table 9. Expected Utility for Most-Preferred Selections

Criterion	Criterion selection	interpreted scale (y)	A_i	B_i	$U(y_i)$	S_i	Common scale utility
1.1	High	100	0.0143	−0.4286	1	0.0586	−0.0586
1.2	1	1	2.5	−1.5	1	0.0111	−0.0111
1.3	Good	100	0.0143	−0.4286	1	0.0049	−0.0049
2.1	High	100	0.0143	−0.4286	1	0.2432	−0.2432
2.2	Tight	100	0.02	−1	1	0.0577	−0.0577
2.3	Low	100	0.02	−1	1	0.0228	−0.0228
3.1	High	100	0.02	−1	1	0.4242	−0.4242
3.2	Tight	100	0.0143	−0.4286	1	0.1269	−0.1269
3.3	High	0	0.0143	−0.4286	1	0.0507	−0.0507
							Total score = 1

Transformation of Utility Values

By multiplying $U(y_i)$ by the S_i corresponding to each criterion i, a common scale utility value is calculated. The common scale utility values of all criteria are summed to produce an expected utility value (total relative score) for a given project scenario. A developed ceiling price (CP) utility function is then used to transform the expected utility value, $Eu(x)$, for a project scenario x into a recommended probability value, denoted as Px. This CP utility function is constructed based on the values of the worst case [$Eu(w)$], threshold-point [$Eu(t)$], and most-preferred [$Eu(p)$] scenarios. As Fig. 3 illustrates, if $Eu(x)$ exceeds the expected utility of the threshold point with a probability of 0.5, then the CP utility function can be derived as follows:

$$\frac{P_x - 0.5}{P_{budget} - 0.5} = \frac{Eu(x) - Eu(t)}{Eu(p) - Eu(t)} \quad (4)$$

Since the expected utility of threshold point $Eu(t) = 0$, Eq. (4) can be modified as

$$P_x = 0.5 + \frac{Eu(x)}{Eu(p)}(P_{budget} - 0.5)\ ;\ Eu(x) > 0 \quad (5)$$

Alternatively, if $Eu(x)$ is less than $Eu(t)$, then the CP utility function can be derived by

$$\frac{P_x - 0}{0.5 - 0} = \frac{Eu(x) - Eu(w)}{Eu(t) - Eu(w)} \quad (6)$$

Once again *Eu* (*t*) = 0, and Eq. (6) can be modified as

$$P_x = 0.5 - 0.5 \left[\frac{Eu(x)}{Eu(w)} \right] ; Eu(x) < 0 \quad (7)$$

Using a probability of 0.5 with respect to *Eu* (*t*) = 0 as a transition point is not essential to establishing the two-straight-line CP utility function. Users may choose values other than 0.5 while still following the transformation procedure described previously. For example, when a user has no preference regarding the value of probability at *Eu* (*t*) = 0, the CP utility function *F*1, displayed in Fig. 3, may be selected. The straight-line *F* 1 can actually be derived from just two points, [*Eu* (*w*), 0] and [*Eu* (*p*), P_{budget}]. In other situations, the user may favor the *F2* or *F3* functions illustrated in the same figure, depending on the probability of making a profit that the user (the ceiling price decision – maker) is willing to give to the contractor.

The F function is used for this application project. Table 8 lists the selections of the worst-case scenario for criteria with the value of Eu (w) calculated to be – 0.7206. Meanwhile table 9 lists the selections of most-preferred scenario, with Eu (p) calculated as 1, the value of the Eu(x) based on the inputs displayed in table 10 is 0.6313. Notably, the value of P_{budget} is 0.96 for this application project. Since Eu(x) > 0, Eq. (5) is applied, and the value of Px is computed as 0.7910.

Results

Determination of Project Ceiling Price

Given the value of Px, the corresponding cost (that is, suggested project ceiling price) can be obtained from the cumulative probability distribution of the project cost by using a straight-line interpolating method. For this project, the two simulated probabilities closest to Px (= 0.7910) are 0.7819 and 0.8380 and they have corresponding project costs of $ 29,333,333 (NT $ 880,000,000/30) and $ 29,500,000 (NT $ 885,000,000/30), respectively. The ceiling price for the project suggested by SIM-UTILITY is thus approximately $ 29,360,367 (NT $ 880,811,000/30).

Table 10. Expected Utility for Example Project Selections

Criterion	Criterion selection	interpreted scale (y)	A_i	B_i	$U(y_i)$	S_i	Common scale utility
1.1	Average	50	0.0143	−0.4286	0.2864	0.0586	0.0168
1.2	0.79	0.79	2.5	−1.5	0.4750	0.0111	0.0053
1.3	Fair	50	0.0143	−0.4286	0.2864	0.0049	0.0014
2.1	Moderately high	75	0.0143	−0.4286	0.6439	0.2432	0.1566
2.2	Moderately tight	75	0.02	−1	0.5	0.0577	0.0289
2.3	Average	60	0.02	−1	0.2	0.0228	0.0046
3.1	Moderately high	80	0.02	−1	0.6	0.4242	0.2545
3.2	Tight	100	0.0143	−0.4286	1	0.1269	0.1269
3.3	Moderately high	80	0.0143	−0.4286	−0.4286	0.0507	0.0363
							Total score = −0.6313

During the opening of bidding for the project, the final ceiling price set by project owner was $ 29,333,333 (NT = $ 880,000,000/30). The New Taiwan dollar ceiling price has been rounded down from the suggested NT $ 880,811,000 to NT $ 880,000,000. Removing additional numbers from the suggested price is common practice to Taiwan and is seen as making the price look tidy. For this project, the results generated by SIM-UTILITY provide valuable information to support the process of determining the ceiling price.

Table 11. Results for Electrical and Mechanical Subprojects

Subproject	Project budget	Simulated minimum cost	Simulated expected cost	Simulated maximum cost	Px	Suggested ceiling price	Eventually determined ceiling price	Lowest bid	Bid ratio	Probability of bid
Electrical	5,332,939	5,101,317	6,281,420	7,375,889	0.02	5,332,939 (159,998,184 NT)	5,330,000 (159,900,000 NT)	4,050,333 (121,510,000 NT)	0.7599	0
Mechanical	3,666,599	3,724,867	4,246,561	4,846,261	0	3,666,599 (109,997,970 NT)	3,663,333 (109,000,000 NT)	2,933,333 (88,000,000 NT)	0.8073	0

Tendering Outcomes

After opening the submitted bids for this project, the lowest bid was found to be U. S. $ 27,666,667 (= NT $ 830,000,000/30) and the project was successfully tendered out. The difference between the ceiling price and the bid was about $ 1,666,666 ($ 29,333,333 — $ = 27,666,667). Meanwhile, the bid ratio was 0.94 (= $ 27,666,667 / $29,333,333), which was satisfactory from the perspective of avoiding accusations of mismanagement. Notably, the probability of profitably completing the project at this bid is only 0.0698, by interpolating from the cost distribution. This low probability is the result of the relatively small range of simulated project costs, between $ 26,664,733 and $31,735,613. Nevertheless, as suggested by SIM-UTILITY, this low probability indicates that the owner should pay careful attention to quality management during project construction.

Applications to other projects

The SIM-UTILITY model was also applied to the electrical and mechanical subprojects of the same building project. Following procedures similar to those used in the architectural project, the results for these two subprojects are also reliable. Table 11 summarizes the results of the budget, Px, suggested ceiling price provided by SIM-UTILITY, eventually determined ceiling price, lowest bid, bid ratio, and probability of profitability at the lowest bid for two projects. Some of the data are presented in NT dollars for ease of interpretation.

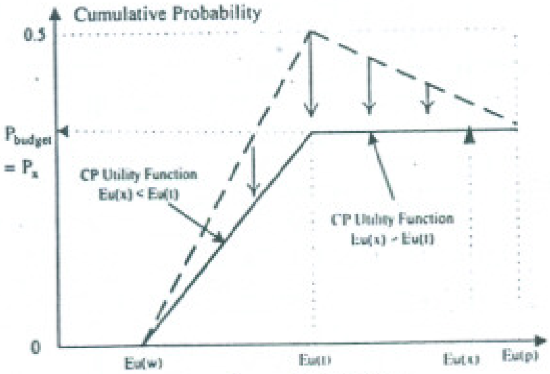

Fig. 4. Ceiling price utility function with P_{budget} < 0.5

Table 11 reveals that in both subprojects, the owner simply removed the superfluous numbers from the price suggested by SIM-UTILITY and took this as the final ceiling price. Meanwhile, both subprojects were successfully tendered. However, the suggested ceiling price in each subproject equals the original project budget. This phenomenon is mainly owing to the project budget being too low, leading to a low P_{budget}. This phenomenon can be best illustreated graphically. According to Fig. 4, since a probability value of 0.5 with regard to Eu(t) is higher than P_{budget}, any value of Px with regard to Eu(t) that exceeds Eu(t) will be higher than P_{budget}. Under the constraint of a fixed project budget, the value of Px must be smaller than or equal to P_{budget}. Thus, the CP utility function must be decreased to reflect reality, as shown in this figure. For a project scenario x with a Eu(t) greater than Eu(t), the value of Px should thus be P_{budget}. (Again, during construction, the simulated cost distributions of the two projects were also presented to the contractors and were considered reasonable).

A low P_{budget} (0.02 and 0 for electrical and mechanical subprojects, respectively) due to the low project budget implies a low ceiling price (which cannot exceed the project budget) with respect to a low Px, subsequently leading to a low probability (0 for both electrical and mechanical subprojects) of profitability at the lowest bid. Thus, suggesting a project budget as the ceiling price with respect to a Px of 0.02 and 0 for electrical and mechanical subprojects, respectively, is what SIM-UTILITY can do best in this case. This lesson highlights the significance of initially providing a reasonable project budget for procuring public projects. The contractors also confirmed that the final costs for both subprojects were greatly overrun after completion, which corresponded to the profitable probabilities of 0 predicted by SIM-UTILITY.

Conclusions

This study has presented a simulation-facilitated utility theory model, SIM-UTILITY. The use of a more objective cost simulation approach to support the definition of the utility value boundaries, and the use of a systematic procedure for evaluating user utility over criteria, provide a systematic model for determining the project ceiling price and thus arising the project tendering process. The modeling results have displayed their strengths by successfully applying the model to three practical construction projects. Future computerization of SIM-UTILITY is expected to significantly boost practices for determining project ceiling prices in Taiwan.

A subsequent paper will present an integrated procedure for comprehensively supporting the owner of public construction projects in dealing with three major owner side, cost-related tasks involved in project tendering. SIM-UTILITY handles the task of determining the project ceiling price, and an electronic unit-price spreadsheet supports the evaluation of competitive bids and helps the negotiation of unbalanced bids under a fixed bid price. Future research on SIM-UTILITY may include exploring ways to incorporate historical cost data to provide more objective statistical distributions of cost components, considering the risk tolerance of the user (which may affect the straight-line assumption of utility functions), and applying SIM-UTILITY to additional construction projects.

DESIGN OF A VOLTAGE SAG REGULATOR FOR PQ MITIGATION

By

N. Khan, N. Mariun and M. R. Ghumman*

ABSTRACT

Voltage sag is one of the most significant power quality problems. The voltage sag problems impact to industrial process because control and protection equipment are sensitive to voltage sag. Electro-magnetic contactor is one of such a devices that is sensitive to voltage sag. Data shows that contactor, which is widely used for controlling motor, cannot work properly when there are 50% rms voltage reduction for a period longer than one cycle. This paper will describe a voltage sag regulator device that is especially use to minimize voltage sag impact at the contactor.

INTRODUCTION

The problem of electric power system has become complex now. It is not just a question of how to generate electrical power and the means of transferring this power, but also about how to maintain the voltage and frequency within certain level suitable for consumer equipment [1]. All the process that was described above must follow several criteria such as reliability, economic viability and quality [2].

The quality of electricity has become an important issue in recent years. The instability of power supply can be caused by disturbances at utility or by consumers, which affects to sensitive equipment. In addition the consumer uses non-linear equipment, which introduce harmonic distortion on the supply.

Surveys have shown that voltage sags are the dominant factor affecting power quality; nearly 92% of the power quality problems are associated with voltage sag. Productivity loss due to deep voltage sags and brief power interruptions has been called "the most important concern affecting most industries and customers", costing billions of dollar every year [3].

Solving power quality problems especially voltage sags can be done on either the utility side or on the consumer side. For example at consumer side many facilities have motors controlled by contactors. While motors often have enough inertia to ride through power line disturbances, contactors have been shown to be particularly susceptible to voltage sags. The data has show motor contactors will drop out at 50 % voltage if the condition lasts for longer than one cycle [4]. This paper will describe mitigation of voltage sag at contactor using voltage sag regulator circuit.

CONTACTOR COIL ENERGIZING

An electromagnetic contactor is a kind of equipment that is sensitive to voltage sag. It can use either an ac or a dc power source to energize its coil. Contactors that draw power from an ac source are more sensitive to voltage disturbances than contractors that draw power from a dc source. The voltage sag regulator is added to mitigation affects of voltage sag at the ac contactor.

The voltage sag regulator operates on the following principle: a contactor designed to operate from an ac voltage source, operates just as well as from a lower dc voltage source. The voltage sag regulator uses this "headroom" between the available ac source voltage and the required dc coil voltage to maintain coil current even when the ac voltage drops [5].

Figure 1 and Figure 2 can be used to explain this principle; when a contactor, operating from an ac source, the coil current Ic(ac) of the contactor is determined by Vc(ac) and $(2\pi f_{ac})L$ because $(2\pi f_{ac})L >> R$.

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$$Ic_{(ac)} = \frac{Vc_{(ac)}}{\sqrt{[(2\pi f_{ac})L] + R}} = \frac{Vc_{(ac)}}{(2\pi f_{ac})L} \qquad (1)$$

$$Ic_{(ac)} = \sqrt{2} Ic_{(ac)} Sin(2\pi f_{ac})t \qquad (2)$$

The coil current exerts a time-varying pulsating force on the contactor armature that depends on the current amplitude. The average force exerted by ac current is proportional to the half-cycle average current.

$$Ic_{(h-c-avg)} = \frac{1}{Tac/2} \int_0^{Tac/2} \left| Ic_{(ac)} \right| dt = \frac{2\sqrt{2}}{\pi} Ic_{(ac)} \qquad (3)$$

Substitution of (3.1) gives

$$Ic_{(h-c-avg)} = \frac{2\sqrt{2}}{\pi} \cdot \frac{Vc_{(ac)}}{(2\pi f_{ac})L} = \frac{\sqrt{2} V_{(ac)}}{\pi f_{ac} L} \qquad (4)$$

In contrast, when the coil is operated from a dc voltage of average value Vc(dc), $(2\pi f_{AC})L = 0$ and the dc coil current Ic(dc) is

$$Ic_{(dc)} = \frac{Vc_{(dc)}}{R} \qquad (5)$$

The dc current $I_{c(dc)}$ exerts a constant force on the armature. For the dc current $Ic_{(dc)}$ to exert the same average force on the armature as the ac current $Ic_{(ac)}$, the ratio of dc voltage to ac voltage found by equating (4) and (3).

$$\frac{Vc_{(dc)}}{Vc_{(ac)}} = \frac{\sqrt{2}}{\pi . f_{ac} L} \qquad (6)$$

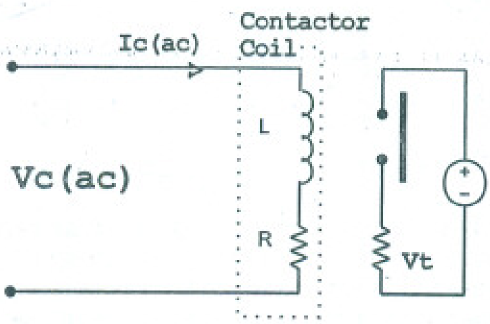
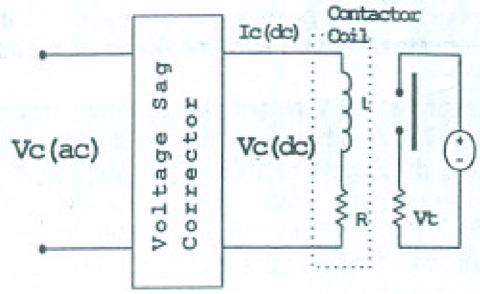


Figure 1: Contactor coil energized by conventional ac source

BASIC CIRCUIT OPERATION

We have followed the theory of Kelley, A and Carovec, J., el al [5] to simulate, design and construct a voltage sag ride-through equipment we have modified above refereed were to make it more useful. The complete circuit of our voltage sag regulator is shown in Figure 2. It consists of six different circuit blocks: the rectifier, internal power supply, chopper, timer-controller, gate driver, and power up reset. Three of them, the rectifier, the timer-controller and the chopper, are the most important in the operation of the circuit. The operation can be described as follows:



(a) Figure 2: Contactor coil energized by voltage sag regulator

The input of the voltage sag regulator circuit is an ac source of about 120 V. The rectifier will convert the input into a dc source. The rectifier circuit has two capacitors in parallel. The capacitors are used to produce better quality dc power output and to reduce the effect of voltage level variation; the performance depends on their charging and discharging characteristics.

The output of the rectifier becomes the input of the timer-controller circuit. The timer-controller circuit employs a 556 timer. It will produce an output in the form of a square wave. This output is the duty cycle, which will drive a switch in the chopper circuit. The duration of the duty cycle will depend on the output of the rectifier circuit. The duty cycle changes in tandem with the change in the output of the rectifier.

The duty cycle will drive a switch in the chopper circuit. A power MOSFET acts as a switch in this case. The chopper will lower the high output voltage of the rectifier. The average output of the chopper is given by the following formula: Va = d Vi., which shows the relationship between the duty cycle, rectifier output and the chopper output.

The overall voltage sag regulator circuit produces an average dc power supply of 12 V that magnetizes the contactor coil.

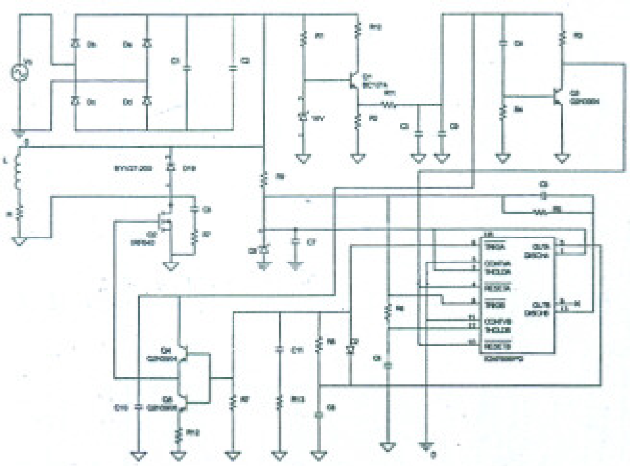


Figure 3: Voltage Sag Regulator Circuit

RESULTS AND DISCUSSION

Our results consist of simulations as well as experimental data

PSpice Simulation Results

The simulation software, OrCad PSpice version 9.1, was used to successfully simulate the voltage sag regulator circuit. The simulation works has shown satisfactory results. Simulation results shows the input voltage Vc(ac), output voltage rectifier, output voltage Vc(dc). The simulations use an input frequency of 50 hertz, which gives a 10-cycle wave in the space of 200ms. The duration of the voltage sag is set at 3-cycles, starting from the 60ms point until the 120ms point.

In a normal operation, a 120 V ac (rms) input is changed into a 170 volt dc output by a full-wave bridge rectifier. The 170 V dc becomes the input of the control circuit, and this control circuit produces an output with a duty cycle of 0.07. This output will then drive a power MOSFET that functions as a switch in the chopper circuit. The power MOSFET will turn on and off, following the duty cycle, causing the chopper circuit to 'chop' its 170V dc input to a 12V dc average. The results showing the input and output voltage is represented in Figure 4 and Figure 5.

Pre-sag or normal condition starts from the period of 0 ms until 60ms, voltage sag occurs from 60ms until 120ms and post-sag condition from 120ms until 200ms. When the voltage sag generator produces forty percent sag, causing the output to drop to 72 V ac, the output of the rectifier becomes 101.8 V dc. The duty cycle, that was 0.07 under normal operation, changes to 0.126 during the voltage sag, and the chopper circuit produces an output of 12V dc average.

At the condition where the sag is at fifty percent, the input voltage into the rectifier is 60V ac and the output of the rectifier is 84.9V. The duty cycle is 0.14 and the chopper circuit reduces the 84.9 V dc output to a 12V dc average. When seventy percent voltage sag occurs, the magnitude of the input voltage of the rectifier is 36 V ac and its output is changed to 50.91V dc. This dc voltage will cause the control circuit to produce an output with a duty cycle of 0.24.

For the maximum voltage sag possible, occurring at ninety percent sag, the magnitude of the input voltage is 12 V ac and the output of the rectifier is 17 V dc. This is shown in Figure 6 and Figure 7. This condition produces an output at the control circuit with a duty cycle of 0.70. -

The results above points to a correlation between the change of the magnitude of the input voltage, caused by voltage sag, and the change of the duty cycle. The duty cycle increase is proportional to the change in magnitude of the voltage sag. This condition is shown in Figure 6(a).

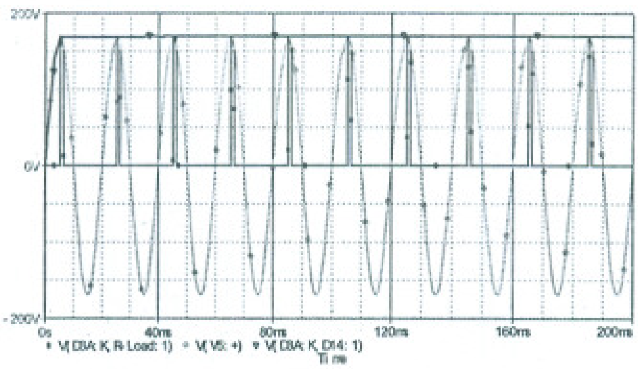


Figure 4: Input voltage Vac and output rectifier at normal operation

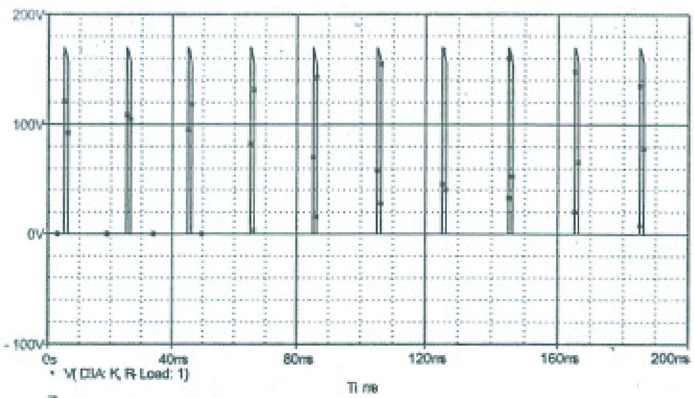


Figure 5: The output voltage Vc(dc) at normal operation

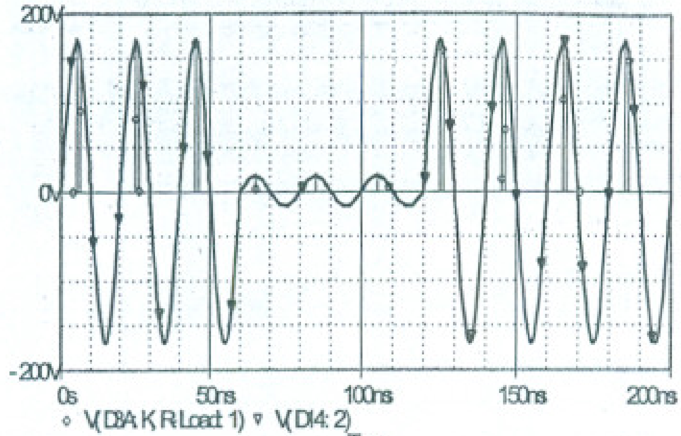


Figure 6; The input voltage Vac at ninety percent voltage Sag

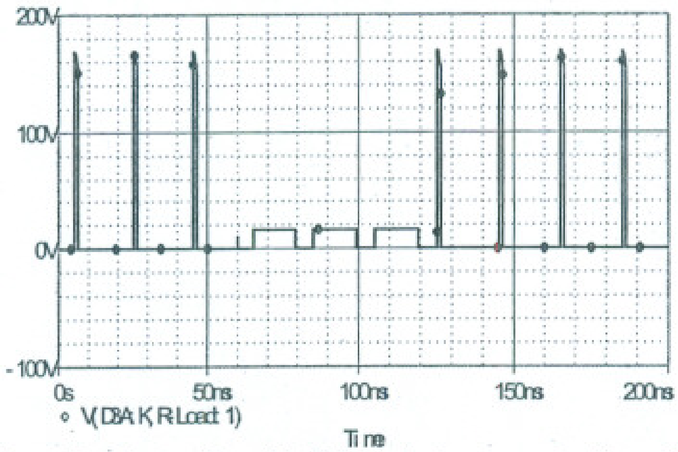


Figure 7: output voltage Vc(dc) at ninety percent voltage Sag

Experimental Results

The results, obtained from the hardware implementation of the voltage sag regulator circuit, is a success because it can regulate an input voltage of up to eighty percent sag. The results were obtained under normal condition and under several critical conditions of voltage sag such as forty percent sag, fifty percent sag, seventy percent sag, and eighty percent sag. The following figures show the output voltage and profile of duty cycle for normal operation and eighty percent condition of voltage sag only.

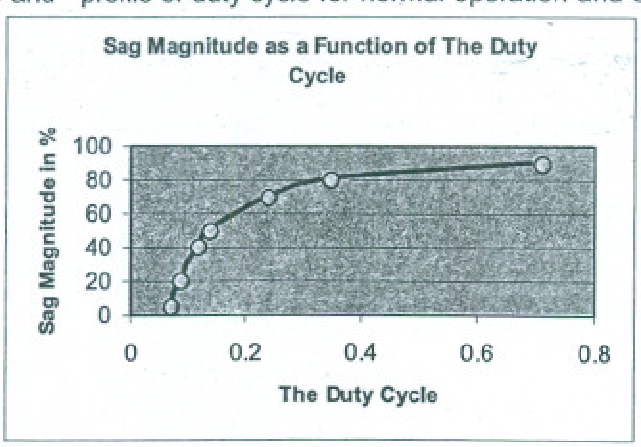


Figure 8: Sag magnitude as a function of the duty cycle for simulation

The voltage sag produce uses variable ac transformer. The ac transformers changes manually and gradually for obtain the magnitude of voltage. In a normal operation, a 120 V ac (rms) input is changed into a 170 volt dc output by a full-wave bridge rectifier. After that, the 170 V dc becomes the input of the control circuit through resistor R_9 and capacitor C_7. The resistor R_9 and capacitor C_7 determine ON time or T_{ON} of the output control circuit.

In normal operation control circuit produce about 0.07 duty cycle, but when the output control circuit is connected with gate of power MOSFET at chopper circuit, the duty cycle change become 0.095. The power MOSFET will turn on and off, following the duty cycle, causing the chopper circuit to 'chop' its 170V dc input to a 16.5V dc average. The results showing the output voltage and duty cycle are represented in Figure 9 and Figure 10.

At the condition where the sag is at forty percent, the input voltage into the rectifier is 72V ac and the output of the rectifier is 123.1V dc. The duty cycle increase becomes 0.13 and the chopper circuit reduces the 123.1V dc output to a 15.9V dc average. When the variable transformer is changed to obtain seventy percent voltage sag occurs, the magnitude of the input voltage of the rectifier is 65 V ac and its output is changed to 114.4V dc. This dc voltage will cause the control circuit to produce an output with a duty cycle of 0.138. The chopper circuit changes the 114.4 V dc output of the rectifier to 15.78 V dc average.

The results above points to a correlation between the change of the magnitude of the input voltage, caused by voltage sag, and the change of the duty cycle. The duty cycle increase is proportional to the change in magnitude of the voltage sag. This condition is shown in Figure 13.

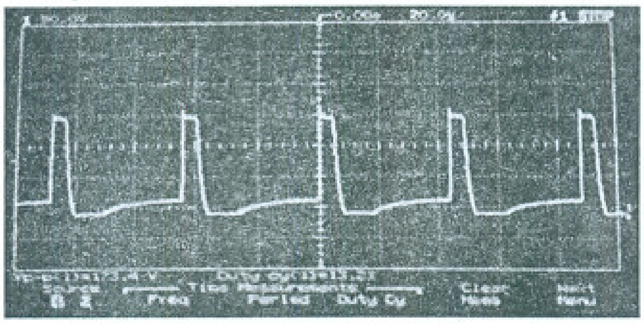


Figure 9: The output voltage Vc(dc) at normal operation

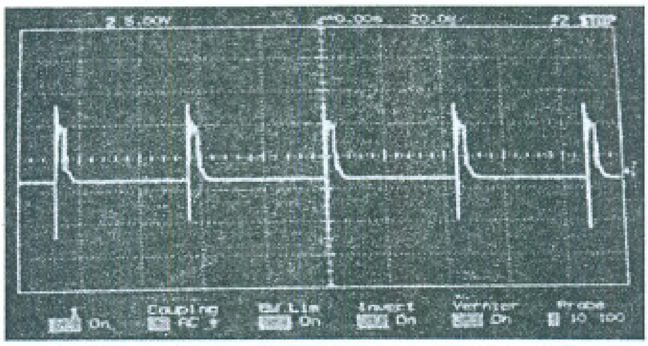


Figure 10: The duty cycle profile at normal operation

When seventy percent voltage sag, the magnitude of the input voltage of the rectifier is 36 V ac and its output is changed to 62.5V dc. This dc voltage will cause the control circuit to produce an output with a duty cycle of 0.202. The chopper circuit changes the 62.5 V dc output of the rectifier to 12.625 V dc average. When variable transformer is changed to minimum voltage until the input voltage is 24V, and the output of the rectifier is 41.67 V dc. This condition produces an output at the control circuit with a duty cycle of 0.288 and this duty cycle will drive the power MOSFET in the chopper circuit, causing it to produce an average output voltage of 12 V dc. Figure 11 and Figure 12 shows the output voltage Vc(dc) and the duty cycle.

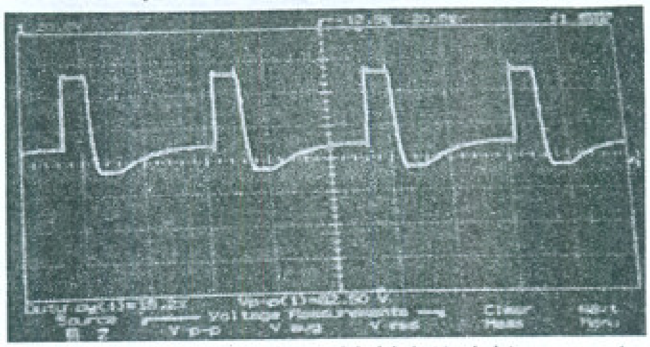


Figure 11: The output voltage Vc(dc) at eighty percent sag

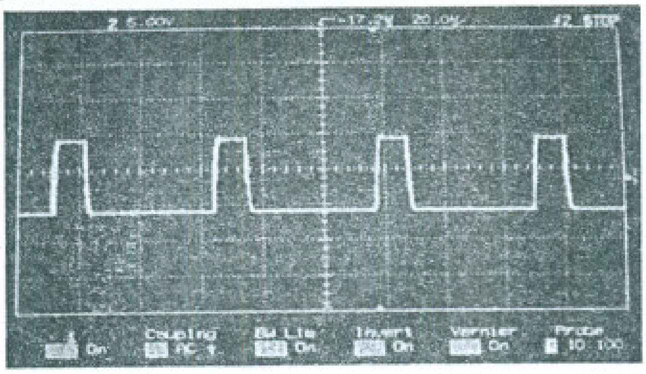


Figure 12: The duty cycle profile at eighty percent Sag

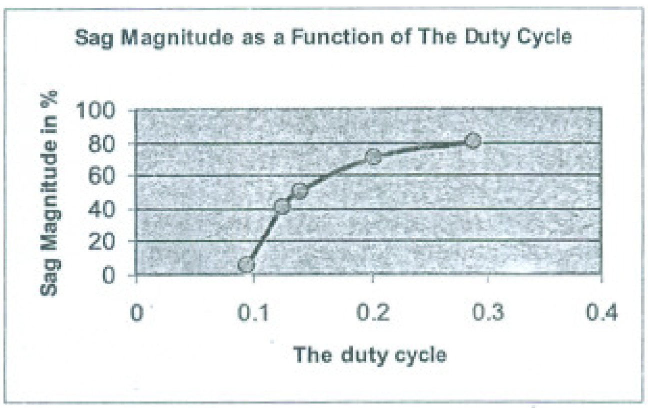


Figure 13: Sag magnitude as a function of the duty cycle for Experimental results

CONCLUTIONS

The software OrCad PSpice version 9.1 is useful to make simulations of the voltage sag regulator circuit, because the simulation result had shown that the voltage sag regulator circuit has the ability to mitigate voltage sag until 90% of its nominal rated value.

In proportion with the simulation, the experimental result shows that the voltage sag regulator has the ability to mitigate voltage sag until 80% of its nominal rated value. The sag regulator equipment was found to restrain continuity of contactor for voltage sags of 20% to 80% magnitudes.

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169 MVA, 220 KV TRANSFORMERS FAILURES CASE STUDY

By

N. Khan, M. R. Ghumman, N. Mariun, and R. H. Zaini*

Abstract

This paper reports the results of three "Cause of Failure" studies on the collapse of three, 220 kV, 169 MVA, Mitsubishi, BBC and CEM made power transformers in 220 kV Substation Ghakhar, WAPDA, Pakistan. These two transformers got damaged one after the other at the same location in parallel with two similarly sized CEM power transformers and the third power transformer of the similar size got damaged just in a routine operation at an other location within the same substation. This six-month study includes, damaged transformers open & short circuit testing, C&DF testing, oil testing and physical inspection of transformers on site. As part of this study SF6 type 132 and 220 kV circuit breakers were tested for contact resistance and open/close time discrepancies. Finally the cause of damage was established to be the possibility of voltage surge resonance on electric power transmission and distribution system, broken earth meshes under transformer and prevention of cooling by oil pumps due to deposited silts.

1. INTRODUCTION

1- 220/132 kV Power Transformer (T-3) got damaged during cloudy weather on May 5, 1994 at 04:09 Hrs in 220 kV Grid Station Wapda Ghakhar. It was a 160 MVA Power Transformer supplying 400A at the time of fault.

2- 220/132 kV Power Transformer (T-3) got damaged during clear weather in February 18, 1998 at 20:02 Hrs in 220 kV Grid Station Wapda Ghakhar. It was a 160 MVA Power Transformer supplying a 150A load at the time of fault.

3- 220/132 kV Power Transformer (T-1) got damaged during clear weather on November 5, 1998 at 09:04 Hrs in 220 kV Grid Station Wapda Ghakhar. It was a 160 MVA Power Transformer supplying a 600A load at the time of fault.

As per operators staff report 132 kV Circuit Breaker GKR-10 controlling GKR-HFZ line tripped along with 220 kV Circuit Breaker D8Q1 controlling 160 MVA Power Transformer. The relays response and indications were observed as follows. The distance relay 7SA5111 (Siemons) operated on B (4), E (5) and Z1 (7). Main Bucholz tripping relay VAJ (GEC) operated. Differential relay DTH (GEC) showed no response. Over current relay 7SJ5001 on 132 kV side showed no response. Control panel indications on enunciator block include main Bucholz trip and Bucholz alarm. As per transmission engineer's report the lines were patrolled but found nothing.

2. ENGINEERING ANALYSIS OF CASE-1

A 220/132 kV Power Transformer (T-3) got damaged during cloudy weather on May 5, 1994 at 04:09 Hrs in 220 kV Grid Station Wapda Ghakhar. It was a 160 MVA Power Transformer supplying 400 A at the time of fault.

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Staff Report:

132 kV Circuit Breaker GKR-10 controlling GKR-HFZ line tripped along with 220 kV Circuit Breaker D8Q1 controlling 160 MVA Power Transformer. The relays response and indications were observed as follows:

Relays Response:
The distance relay 7SA511(Siemons) operated on B (4), E (5) and Z1 (7).
Main Bucholz tripping relay VAJ (GEC) operated.
Differential relay DTH (GEC) showed no response.
Over current relay 7SJ5001 on 132 kV side showed no response.
Indications Appeared:
Main Bucholz and Bucholz alarm on annunciation block.
Transmission Engineer's Report:

Patrolled the line for 14 Hrs and but found nothing. However, the residents of area saw a strong sparking near third tower, nearly 899 m from the Grid Station.

Protection Engineer's Report:
Tested 220/132 kV Power Transformer T-3 and found grounding of tertiary winding.

The equipment was got tested in presence of P&I staff to determine the defective part of the equipment. The tests include open circuit test, breaker contact resistance measurement, breakers open/close time measurements, transformer turns ration test and dielectric strength tests. The testing results are self explanatory and shown in Tables 1-5. The cause was established to be voltage surge resonance described in detail elsewhere [1].

Table 1 Open circuit test results

Phases	R-N	Y-N	B-N	R-Y	Y-B	B-R
Voltage	182	388	97	377	424	281

Table 2 Breaker contact resistance

Phases	R	Y	B
EHV CB	49 μΩ	46 μΩ	46 μΩ
HV CB	44 μΩ	414 μΩ	43 μΩ

Table 3 Breaker opening/closing times

Phases	R	Y	B
EHV CB Opening time	30 ms	30 ms	30 ms
EHV CB Closing time	145 ms	145 ms	145 ms
HV CB Opening time	49.2 ms	48.5 ms	48.5 ms
HV CB Closing time	96.2 ms	94.1 ms	93.4 ms

Table 4 TTR Test results

Tap	R-N/r-n	Y-N/y-n	B-N/b-n	Tap	R-N/r-n	Y-N/y-n	B-N/b-n
1	1.813	1.0	1.095	13	1.656	1.0	1.013
2	1.800	1.0	1.087	14	1.642	1.0	1.006
3	1.787	1.0	1.079	16	1.617	1.0	0.990
4	1.777	1.0	1.063	17	1.603	1.0	0.980
5	1.759	1.0	1.055	19	1.576	1.0	0.965
6	1.747	1.0	1.041	20	1.563	1.0	0.957
7	1.733	1.0	1.036	22	1.537	1.0	0.943
8	1.721	1.0	1.029	24	1.524	1.0	0.937
9	1.708	1.0	1.029	26	1.485	1.0	0.919
10	1.693	1.0	1.029	27	1.472	1.0	0.914
11	1.681	1.0	1.023				

Table 5 Meggor results (With 5 kV hand operated Meggor)

Connection Type	Resistance (MΩ)
H + L - G	700
H + L - T	700
T - G	0.00

It means the tertiary is short circuited to ground.

3. ENGINEERING ANALYSIS OF CASE-2

A 220/132 kV Power Transformer (T-3) got damaged during clear weather on February 18, 1998 at 20:02 Hrs in 220 kV Grid Station Wapda Ghakhar. It was a 160 MVA Power Transformer supplying a 40A load at the time of fault.

Staff Report:

132 kV Circuit Breaker GKR-10 controlling GKR-HFZ line tripped along with 220 kV Circuit Breaker D8Q1 controlling 160 MVA Power Transformer. The relays response and indications observed are as follows:

Relays Response
220 kV Breaker D8Q1:
Main Bucholz tripping relay along with VAJ (GEC) operated.
Main Bucholz alarm.
132 kV Breaker GKR10:
The distance relay 7SA511(Siemons) operated on B-E and Zone 1.
Indications Appeared:
Main Bucholz and Bucholz alarm on the annunciation block.
Distance relay operated.
Transmission Engineer's Report:
Patrolled the line but found nothing.
Protection Engineer's Report
Tested 220/132 kV Power Transformer T-3 and found it damaged.
Maintenance Engineer's Report
Checked the grounding mesh and found the ground open circuited.

The equipment was got tested in presence of P&I staff to determine the defective part of the equipment. The tests include short circuit test, open circuit test, breaker contact resistance measurement, breakers open/close time measurements, C & DF test, transformer turns ration test and dielectric strength tests. The testing results are self explanatory and shown in Tables 6-11.

Table 6 Short circuit test results

Tap	I_R	I_Y	I_B	I_r	I_y	I_b
12	4.87 A	4.79 A	4.79 A	8.14 A	8.10 A	8.00 A
13	5.03 A	4.97 A	4.96 A	8.41 A	8.36 A	8.36 A
8	4.10 A	4.03 A	4.05 A	7.08 A	7.05 A	7.04 A
2	3.22 A	3.15 A	3.11 A	5.37 A	5.70 A	5.70 A
17	6.03 A	5.94 A	5.94 A	9.75 A	9.70 a	9.68 A
18	6.32 A	6.35 A	5.78 A	10.1 A	10.1 A	10.1 A
20	6.87 A	6.82 A	6.80 A	10.8 A	10.8 A	10.8 A
28	8.12 A	8.02 A	8.07 A	12.4 A	12.4 A	12.4 A
26	8.70 A	8.73 A	8.74 A	13.1 A	13.1 A	13.2 A

Table 7 Open circuit test results

Tap	r-y	I_{exc}	y-b	I_{exc}	r-b	I_{exc}
16	250 V	111 mA	251 V	54 mA	249 V	-
14	246 V	108 mA	248 V	53 mA	244 V	-
12	243 V	108 mA	243 V	51 mA	241 V	-

Table 8 TTR test results

Tap	R-N/r-n	I_{exc}	Y-N/y-n	I_{exc}	B-N/b-n	I_{exc}
12	1.654	0.21 mA	1.685	0.25 mA	1.686	0.27 mA
13	1.646	0.20 mA	1.673	0.23 mA	1.673	0.24 mA
14	1.633	0.23 mA	1.658	0.24 mA	1.660	0.23 mA

Table 9 Breaker contact resistance

Phases	R	Y	B
EHV CB	27 $\mu\Omega$	28 $\mu\Omega$	36 $\mu\Omega$

Table 10 Breaker opening/closing times

Phases	R	Y	B
EHV CB Opening time	28.8 ms	28.8 ms	29.1 ms
EHV CB Closing time	139 ms	142.4 ms	140.8 ms

Table 11 Meggor results

Connection type		Resistance
LV + HV – G	=	700 MΩ
HV + LV – T	=	700 MΩ
T- G	=	Short circuited

High voltage testing results were found out of range for 12, 13 and 14 number tap positions for the red phase. Similarly meggor results for T-G were found short-circuited.

4. ENGINEERING ANALYSIS OF CASE-3

A 220/132 kV Power Transformer (T-1) got damaged during clear weather on November 5, 1994 at 09:04 Hrs in 220 kV Grid Station Wapda Ghakhar. It was a 160 MVA Power Transformer supplying a 600A load at the time of the fault.

Staff Report:

The 220 kV Circuit Breaker D6Q1 and 132 kV Circuit Breaker GKR-71, controlling 160 MVA Power Transformer T-1 tripped simultaneously. The relays response and indications were observed as follows:

Relays Response:
The differential relay D202 (BBC) operated.
CTIG BF relay (GEC) 39 BF operated.
CDG O/C and E/F relay (GEC) showed no response.
CDG tertiary relay (GEC) showed no response.
CAG REF relay (GEC) showed no response.
Indications Appeared:
Main Bucholz alarm and trip on annunciation block of HV side only.
Transmission Engineer's Report:
Patrolled the lines but found nothing. Could be a transformer internal fault.
Protection Engineer's Report:
Tested the power transformer and found it damaged.
Maintenance Engineer's Report:
Tested the power transformer and found the earth weak.

The equipment was got tested in presence of P&I staff to determine the defective part of the equipment. The tests include short circuit test, open circuit test, breaker contact resistance measurement, breakers open/close time measurements, C & DF test, transformer turns ration test and dielectric strength tests. The testing results are self explanatory and shown in Tables 12-16.

Table 12 C&DF test results

Mode (Connection)	Capacitance (F)	DF (%)
CH2+CHG	0.0106	0.35
C1+G	0.0056	0.335
C1+L	0.005	0.39
C2-G	0.01	0.31
CLI+CL	0.0150	0.343

Table 13 Meggor (5kV) insulation testing

From - To	Resistance (MΩ)
(HL) - T	150
(HL) - G	150
T - G	150

Dielectric strength found OK.

Table14 Short circuit test results

Tap	I_R(A)	I_r (A)	I_Y(A)	I_y(A)	I_B(A)	I_b(A)	I_n(mA)
1	4.37	6.5	4.4	6.5	4.37	6.5	0.81
2	4.42	6.7	4.45	6.7	4.44	6.6	0.79
3	4.44	6.83	4.51	6.85	4.48	6.82	0.77
4	4.52	6.99	4.56	7.06	4.54	6.98	0.76
5	4.58	7.16	4.63	7.16	4.6	7.18	0.74
6	4.64	7.28	4.69	7.33	4.66	7.28	0.77
7	4.69	7.39	4.73	7.48	4.71	7.39	0.71
8	4.73	7.53	4.78	7.54	4.76	7.49	0.69
9	4.77	7.65	4.83	7.7	4.79	7.61	0.69
10	4.80	7.7	4.88	7.82	4.85	7.78	0.66
11	4.88	7.92	4.92	8.0	4.89	7.94	0.65
12	4.92	8.02	4.92	8.1	4.92	8.08	0.64
13	4.96	8.17	4.99	8.24	4.96	8.17	0.62
14	4.99	8.26	5.01	8.32	4.92	8.26	0.61
15	5.01	8.39	5.05	8.46	5.04	8.41	0.58
16	5.04	8.48	5.11	8.52	5.05	8.45	0.56
17	5.04	8.58	5.11	8.67	5.06	8.6	0.53
18	5.05	8.68	5.11	8.76	5.06	8.69	0.50
19	5.04	8.75	5.12	8.8	5.1	8.74	0.47
20	5.03	8.79	5.13	8.88	5.1	8.84	0.44
21	5.04	8.85	5.12	8.97	5.09	8.91	0.41
22	5.05	8.94	5.12	9.06	5.06	8.99	0.39
23	5.04	8.99	5.12	9.08	5.09	8.04	0.37
24	5.03	8.04	5.12	9.11	5.09	9.09	0.34
25	5.04	8.11	5.11	9.21	5.08	9.12	0.33
26	5.0	9.03	4.96	9.21	5.04	9.12	0.30
27	4.91	9.17	5.07	9.21	5.01	9.22	0.28

Table 16 TTR test results

Tap	AN/an	BN/bn	CN/cn
1	1.655	1.479	1.490
2	1.647	1.492	1.502
3	1.663	1.505	1.514
4	1.530	1.517	1.526
5	1.552	1.530	1.532
6	1.566	1.543	1.552
7	1.579	1.555	1.565
8	1.597	1.568	1.578
9	1.605	1.582	1.592
10	1.617	1.595	1.605
11	1.630	1.607	1.617
12	1.647	1.620	1.630
13	1.655	1.633	1.642
14	1.667	1.645	1.655
15	1.682	1.657	1.667

16	1.694	1.667	1.682
17	1.707	1.684	1.695
18	1.719	1.698	1.707
19	1.732	1.710	1.719
20	1.744	1.722	1.732
21	1.756	1.722	1.744
22	1.769	1.731	1.757
23	1.783	1.743	1.770
24	1.789	1.752	1.783
25	1.795	1.766	1.797
26	1.808	1.780	1.810

5. CONCLUSIONS

Engineering analysis based on various types of tests, field data, inspection of site, discussion with the local staff at 220 kV substation Ghakkhar and personal experience in power industry, it was concluded that the causes of failure of three 160 MVA power transformers were as follows:

In **case-1** the transformer was damaged due to lightning in a thunderstorm day. The length of ILnex conductor involved from the occurrence of lightning and transformer was about 800 meters. The conductor impedance was $Z_1 = Z_2 =$).1583 + j 0.400 Ω/km and Z_o = 0.3246 + j 1.228 Ω/km. The overall line length was about 80 km. The line crossed the 220 kV line at about 800 meters from the substation. There was no shield wire over this crossing. The voltage was believed to integrate under Bewly voltage build up scheme. However, voltage surge resonance also has the similar probability of occurrence.

For **Case-2** the transformer was damaged by a severe three phase to ground short circuit fault on one of the 132 kV line. The testing and physical inspection could not conclude anything so the digging of transformer grounding mesh was conducted that showed a broken/rusted joints on the grounding mesh. The cause of damage is believed to be the broken grounding joints that could not handle the extraordinary currents during phases to ground fault.

In **Case-3** the power transformer had got damaged during its normal operation in good ambient weather. Initial testing and inspection could not conclude anything so the internal inspection was carried out adopting special means. The oil was removed from the tank and found a deep layer of silt/mud/wax that had practically prevented the oil circulation. The oil pumps were unable to circulate the oil through the radiator. The temperature gauges were found defective.

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