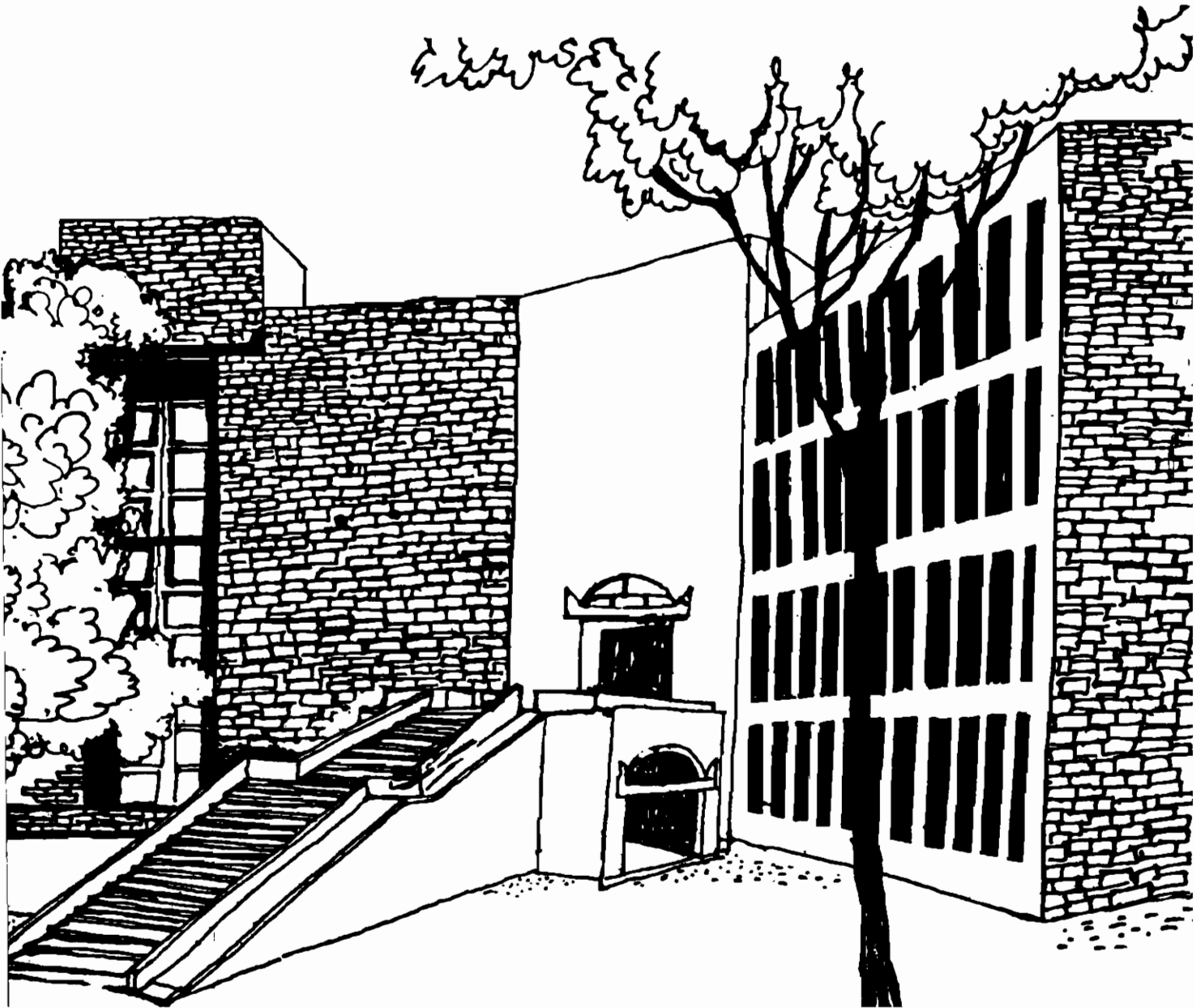




Working Paper



COMPUTER SIMULATION OF HOSPITAL SYSTEMS

By

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W.P. No. 98-07-03

July 1998/~~459~~ 1460

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Computer Simulation of Hospital Systems

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1. **Research Objectives:** The objectives of our research study are:
 - (i) Undertake a comprehensive systems analysis of a hospital department such as outpatient department, inpatient department, etc.
 - (ii) Design and develop a computer simulation model, validate the model and conduct simulation experiments for the selected department,
 - (iii) Analyse various options available to the department in the hospital for providing its services, and evaluate the impact on hospital performance indicators,
 - (iv) Redesign/Re-engineer the existing systems if required in order to provide a desired level of service.

In our study, we have chosen to design and develop a simulation model for the Medicine Outpatient Department (Med OPD) at the Christian Medical College Hospital (CMCH) Vellore.

2. Research Methodology

Systems Analysis: Our first step in this research project is to undertake a detailed systems analysis to understand the functioning of the OPD department in the CMCH.

Simulation Modelling: We rely on Discrete Event Simulation methodology for modeling the existing systems in the hospital under study. Simulation models are used either when analytical models cannot satisfactorily capture the realities of the system under study or when analytical models cannot provide closed form solutions for implementation in the organisations. It is well known that hospital systems are too complex to be modelled analytically and therefore we propose to build simulation models to understand and analyse the system in sufficient detail to enable hospital management to address significant issues. Our simulation models will enable us to evaluate the impact of several alternative processes on the performance of the system under study.

Business Process Re-engineering: We adopt a Business Process Re-engineering (BPR) approach to redesign/re-engineer the existing processes and procedures as an integrated system based on the results from the simulation models. In BPR, the analysis is always done on the system or business unit as a whole (business processes) and not at the level of any individual operation or function in the system under study. (In contrast, traditional analysis addresses the concerns at individual functions or operations and invariably fails at the time of arriving at an integrated solution for the system as a whole). BPR methodology is therefore a radical approach, but assures dramatic improvements in system performance upon implementation. Hospitals which have reengineered some of their traditional systems have benefited extensively.

Data Collection: Our methodology involving Simulation and BPR calls for collection of data through an appropriately designed sample survey. Data should be collected on the activities in the hospital systems (for Simulation modelling) and the current practises and procedures being followed in the hospital (for BPR application).

Model Validation: The task of ensuring that the model adequately represents the system under study is normally split into two phases. The first phase, verification, is the process of ensuring internal consistency of the model. Regardless of the model's ability to mimic the target system, the model should behave in the manner which the model creator intended. The second phase, validation, however is a more difficult task. Validation requires the model to adequately mimic the target features of the modelled system. This step involves interaction with the hospital authorities to gain an appreciation of and comment on the dynamics and process flow of the system being modelled.

Model application: The credibility of a simulation model will depend on the rational validity of the model and the organisational context of the model. The model however will also need to be legitimate in the eyes of the key stakeholders in the decision process which the model is intended to inform. This will flow from the inclusion of these stakeholders in the model development and validation process.

3. Outpatient Services at CMCH: Outpatient services at CMCH is offered over 40 different clinics covering a number of specialties, supported by a comprehensive range of investigation facilities. The load on OPD can be seen from the data given in Exhibit 1.

Any outpatient coming to CMCH has the option of being a Private patient or a General patient. Private patients meet their preferred consultant in the appropriate clinic by prior appointment, while general patients are seen by any doctor available in the clinic on the day of their arrival. After registering as a private or a general patient, all outpatients go through the same activities, namely, Registration, Consultation, Payment, Investigation and Medication .

Registration Every new patient coming into the hospital is registered and is given a unique hospital number. Having received this number, the patient then enters the Outpatient System. The patient is then given an appointment to see a doctor. This appointment specifies the location of the clinic, the date and approximate time of consultation, and the name of the doctor who will be seeing the patient. All visits to doctors can be only by registration.

Consultation: On arriving at the clinic, the patient first reports to the Medical Records Officer, who ensures that the chart is ready and then informs the doctor that the patient is waiting. After being examined by the doctor, the patient is advised to do one or more of the following: undergo investigations to aid diagnosis, take medications, consult other specialists for opinion/evaluation, return for a repeat consultation, admitted for treatment.

Each advise given generates its own set of events. Since not all doctors sit in the outpatient clinics on a daily basis, referrals and repeat registrations can be done only for days when the particular clinic or doctor is available.

Payment: The investigations and medicines advised by the doctor are paid for at the Common Payment Facility (CPF). After payment, the patient is directed to proceed for investigation and collect the medicines. The patient may also register for the next visit at this time.

Investigation: When the doctor recommends that investigations are necessary, the patient enters the investigation phase. The investigation phase consists of sample collection and sample analysis.

Sample Collection: There are a number of laboratories which are involved in the investigation process. Most of them have a common Central Sample Collection Facility (CSCF), where the samples for testing (blood, urine, etc) are collected. From here they are transported to the appropriate laboratory. The radiodiagnostic tests are done at a separate facility. There are some special tests for which the sample collection is done at the laboratory.

Sample Analysis : There are about 20 laboratories performing various investigations needed for OPD diagnosis. At the laboratory, the samples are processed and the results are fed into the Local Area Network (LAN). These reports are accessed by the Medical Records Department and affixed in the charts, where they are available at the time of the patients' next visit. The reports remain available for a limited period of time on LAN and are accessible to different clinics during this time.

Requests for Imaging services are treated differently. After initial processing, the films have to be seen by the radiologists and interpreted. The films along with the reports are sent to the clinics from which they were ordered. They are available for the doctor to see on the patient's next visit.

Medication : The medicines prescribed by the doctors can be purchased from the hospital pharmacy after making the necessary payment at the Common Payment Facility. They can also be purchased at pharmacies situated outside the hospital.

It should be realised that some of the processes mentioned above may run simultaneously. For example, the medication process and the investigation process may begin simultaneously after the first consultation, and both may continue through subsequent consultations.

The duration of a patient's stay in OPD depends on the kind of tests ordered, the outpatient schedule of the primary doctor, the outpatient schedules of the doctors referred to, and the number of revisits needed to complete the consultation and investigation process.

(a) **The kind of tests ordered:** The availability of results varies with the kind of tests ordered. In addition to the sample processing time, the work schedule of the laboratory and that of the Central Sample Collection Facility would also affect the availability of results. The availability of test results determines when the doctor will be able to see the patient again.

b) **The outpatient schedule of the primary doctor:** The outpatient schedule of the primary doctor determines when he/she can review the investigations advised and the opinions requested from other doctors.

c) The outpatient schedules of the doctors the patient is referred to. The pattern becomes more complicated when more than one doctor is involved. Then the patient goes through the cycle with each of the doctors, each doctor may advise additional investigations. Revisits for interpreting the results of those investigations would be determined by his/her outpatient schedule. As a result, the cross-referrals requested can prolong the duration of outpatient stay.

d) The number of revisits needed before the patient completes his/her consultations with a particular doctor. This is a reflection of the complexity of the patient's problem. A patient with a more complicated problem would need a larger number of revisits before his/her problem is resolved. At the end of the outpatient visit, when a final diagnosis is made and treatment recommended, the patient leaves the system till the next follow-up or the next illness episode.

4. Outpatient Services in Medicine Department at CMCH:

Medicine department at CMCH offers OPD services from Monday through Saturday every week. For administrative convenience, the department is divided into three independent clinical units, Medicine I, II, and III. Each unit has its own set of doctors and follows its own work culture. Each unit has a fixed number of beds for admitting inpatients and fixed days for seeing outpatients. The appointment scheduling system gives flexibility to the doctors to work according to their preferences. Each unit can also specify the mix of patients (number of new and repeat cases) to be seen on its OPD days. All patients registered before 11 am on the OPD days are seen by the unit, even if it means extended OPD hours for the unit. Every outpatient stays with his/her doctor (and hence the same unit) till the treatment is completed. As a result, if a new patient registers with Medicine Unit I, his/her repeat visits can be scheduled only on the days when Medicine Unit I has its OPD hours. Unit I is responsible for Tuesday and Friday OPD clinics, Unit II is responsible for Monday and Thursday OPD clinics, while Unit III looks after Wednesday and Saturday OPD Clinics. Each unit follows a three day cycle, twice a week, with one full day for OPD Clinics and the other two days for other activities which include inpatient care, teaching and research.

In order to analyse the OPD process mentioned above, we collected data on the actual flow of outpatients in the Medicine OPD units I, II, and III. We collected data on the flow of only the private outpatients, since the OPD process flow is the same for private and general patients as mentioned earlier (The only difference between a private and general patient is that the former pays higher consultation charges to meet his/her preferred consultant, while the latter pays less and is seen by any doctor available in the clinic).

For each patient visiting the medicine OPD, we collected the following data on each visit.

Patient ID particulars

Time of Registration on the day of consultation

Patient visit number

Time for Appointment with the doctor given by the registration clerk

Time consultation starts, ie time when the patient is called into the clinic

Time consultation ends, ie time when the patient exits from the clinic

Consultation outcomes: Referred to Dept name, admitted inpatient, medicines prescribed, investigations ordered.

List of tests for investigations, such as blood sugar, Xray etc
Time payment made for tests and /or medicines
Time when the samples were given for investigation, eg blood, urine samples etc
Time when the sample results are ready
Special remarks

Registration : Analysis of the registration phase focuses on identifying the arrival pattern of patients at the registration desk. Any patient registering before 11 am is given an appointment time with his/her consultant for the same day.

Consultation : The consultation process for each visit results in different outcomes, such as referred to another department, admitted as inpatients, medication prescribed, and/or investigations ordered. It is therefore necessary to analyse the consultation process for each visit separately. It is also necessary to analyse the working of each unit separately since each med unit follows its own work culture. The analysis described below is repeated for each visit for each unit.

An understanding of the load on the investigation laboratories placed by the medicine units I, II, and III is essential in order to analyse the consultation process in detail. For illustration, Exhibit 2 provides a profile of the tests/investigations ordered by Unit I in each laboratory for their outpatients on their first visit. It can be seen that most of the OPD diagnosis is performed in four laboratories, namely clinical pathology, biochemistry, microbiology and radiology. The most commonly performed tests in each of these labs are also listed in this exhibit. Exhibit 3 shows the number of tests per patient in each laboratory ordered by Unit I. Exhibit 4 gives the total number of tests per person (across all laboratories) for medicine units

Payment: Our observations from the sample data shows that the patients complete the payment process within 15-30 minutes after consultation.

Sample Collection: After making the payments, patients proceed to the sample collection centres for giving samples (urine, blood etc) for analysis and the Radiology department for X-rays if required. These activities are not properly coordinated in the existing system leading to delays in giving the samples. These delays are over and above the delays on account of the nature of the tests; for example, blood samples for detecting blood sugar can be given only on the morning after consultation since the patient is required to observe fasting overnight.. Only about 70 percent of the outpatients give samples on time. About 20 percent delay by 1 day, and another 10 percent delay by as much as 2 days in giving the samples. Delays in giving samples leads to delays in the availability of test results which in turn may delay the treatment completion time.

Sample Analysis: Test results from sample analysis are mostly available within 24 hours of giving the sample, except in the case of certain microbiology tests which require culture analysis. From this information, we estimated the time when results from all the tests for each outpatient will be ready, based on the record of tests done on each outpatient. Results from all the tests are ready latest by the evening of the day after consultation for almost 60 percent of the cases. If the samples are given on time, the above comment will be applicable for 80 percent of the cases. It will take

more than 2 or 3 days to get all the test results for the remaining 20 percent of the outpatients because of the nature of the sample analysis (eg. culture analysis in the microbiology laboratory).

5. A Simulation Model for the Med-OPD Process:

Based on an understanding of the medicine OPD process given above, we designed and developed a Monte Carlo Simulation Model to analyse the existing and alternate OPD processes at CMCH. The logic of our simulation model is briefly given below.

For each patient N (N = 1,2,3,.....)

DO : Generate the time of registration

Generate the visit number i , $i = 1,2,3,4$

For each visit number i

DO : Consultation :

Record the time consultation starts.

Compute the waiting time for consultation.

Generate the consultation time

Generate the labs involved in OPD diagnosis

For each lab, generate the tests ordered

Record the time consultation ends.

Payment :

Generate the payment time

Investigation :

Record the time samples given in SCF

For each test in each lab, Compute the time test results will be ready

Compute the time all test results will be ready

End

End.

Validation of our simulation model was then established by comparing the simulation output with the actual working of the medicine OPD units for a period of time. This included simulating the investigation profile of 500 private and general outpatients in the medicine OPD. Based on the simulated profile, we then derived the probability distribution for the number of tests per patient similar to those given in exhibits 3 and 4 for each medicine unit. These two sets of probability distributions were then found to be statistically same by applying the Kolomogorov Smirnov test.

Using the simulation model described above, we evaluated several OPD processes, and the following OPD process is proposed for improving the quality of outpatient services at medicine OPD, which leads to a reduction in the average turnaround time of outpatients.

Existing OPD process (Unit 1)

Day	AM	PM
Monday		
Tuesday OPD	
Wednesday		
Thursday		
Friday OPD	
Saturday		

Proposed OPD Process (Unit 1)

Day	AM	PM
Monday		... OPD ...
Tuesday OPD	
Wednesday		
Thursday		... OPD ...
Friday	... OPD	
Saturday		

Acknowledgements

I am grateful to the Research and Publication Committee of the Indian Institute of Management, Ahmedabad, for the financial assistance provided for carrying out the study. I am also thankful to Dr. Vijay Aruldas of CMC Hospital, Vellore for providing me the necessary information to understand the outpatient services at CMC and Ms Anju Yadav, IIM, Ahmedabad for her assistance in computer programming.

Exhibit I
OPD Load at CMCH 1995-96

Units	New Patients			Repeat Patients			Gen-Pvt	% Load
	General	Private	Total	General	Private	Total	Total	
Cardiology I & II	1538	3073	4611	22599	9887	32486	37097	5.7 %
Casualty	12472	0	12472	12906	0	12906	25378	3.9 %
Child Health I & II	4018	1633	5651	40270	6248	46518	52169	7.9 %
Clin. Gastro & Hepa.	369	2649	3018	10816	7887	18703	21721	3.3 %
Dental	1451	437	1888	16294	1511	17805	19693	3.0 %
Dermatology	3050	1297	4347	14069	1904	15973	20320	3.1 %
Disbetic Clinic	2	0	2	3112	87	3199	3201	0.5 %
Endocrine	229	613	842	5072	3229	8301	9143	1.4 %
Epilepsy	17	0	17	2266	2	2268	2285	0.4 %
ENT	3270	2367	5637	22361	7399	29760	35397	5.4 %
Gynecology I, II & III	6257	2892	9149	46946	16827	63773	72922	11.1 %
Gyn. Oncology	1	1	2	98	6	104	106	-
Haematology	268	646	914	2780	1332	4112	5026	0.8 %
Hansen's Disease	1	0	1	2008	0	2008	2009	0.3 %
Hepatology	15	60	75	862	308	1170	1245	0.2 %
HLRS	329	135	464	5140	719	5859	6323	1.0 %
HRIC	0	0	0	1821	0	1821	1821	0.3 %
ICWC (F.P.)	0	0	0	2048	0	2048	2048	0.3 %
I.D. Clinic	17	3	20	847	0	847	867	0.1 %
Medicine I, II & III	10809	6051	16860	57792	17338	75130	91990	14.1 %
Medicine (T.B.)	4	0	4	774	0	774	778	0.1 %
Neonatal	6236	0	6236	0	0	0	6236	1.0 %
Nephrology I & II	533	1205	1738	4277	2954	7231	8969	1.4 %
Neurology & Neurosur.	1946	3983	5929	17839	7233	25072	31001	4.7 %
Orthopaedics I & II	4160	3302	7462	31315	10356	41671	49133	7.5 %
Paediatric Endocrine	57	8	65	1384	95	1479	1544	0.2 %
Paediatric Surgery	504	199	703	4335	512	4847	5550	0.8 %
Plastic Surgery	166	167	333	1644	256	1900	2233	0.3 %
Post Partum	0	0	0	878	0	878	878	0.1 %
Psychiatry I & II	53	0	53	5195	0	5195	5248	0.8 %
Physical Med. & Reha.	198	84	282	25649	705	26354	26636	4.1 %
Repro. Medicine	230	215	445	665	591	1256	1701	0.3 %
Radiation Therapy	170	246	416	8769	2365	11134	11550	1.8 %
Surgery I, II & III	2720	1879	4599	22867	6817	29684	34283	5.2 %
SSHS	665	0	665	37564	0	37564	38229	5.8 %
Thoracic I, II & III	81	239	320	962	264	1226	1546	0.2 %
Urology I & II	1277	1592	2869	9682	6209	15891	18760	2.9 %
Wellcome Unit	2	0	2	0	0	0	2	-
Total	63115	34976	98091	443906	113041	556947	655038	100 %

Exhibit 2
Profile of Lab Investigations ordered by Medical Unit 1 : Visit 1

Test ID	Clinical Pathology		Clinical Biochemistry		Microbiology		Radiology		Cardio Function		Others *						
	%age all	%age tested	Test ID	%age all	%age tested	Test ID	%age all	%age tested	Test ID	%age all	%age tested	Test ID	%age all	%age tested			
1001	80.00	91.80	3001	45.71	53.33	4001	1.41	7.69	5001	0.00	0.00	6001	24.29	100.00	7012	0.00	0.00
1002	87.14	100.00	3008	0.00	0.00	4008	4.23	23.08	5007	57.75	85.42	6002	4.29	17.65	7022	0.00	0.00
1003	1.43	1.64	3011	2.86	3.33	4013	9.86	53.85	5013	4.23	6.25	6004	0.00	0.00	7031	2.82	10.00
1004	54.29	62.30	3014	0.00	0.00	4015	1.41	7.69	5014	1.41	2.08				9001	1.41	5.00
1005	10.00	11.48	3015	77.14	90.00	4018	0.00	0.00	5020	2.82	4.17				9002	0.00	0.00
1006	61.43	70.49	3016	15.71	18.33	4023	4.23	23.08	5021	1.41	2.08				33000	2.82	10.00
1007	81.43	93.44	3017	2.86	3.33	4029	7.04	38.46	5025	0.00	0.00				40011	0.00	0.00
1009	78.57	90.16	3019	62.86	73.33	4166	0.00	0.00	5029	2.82	4.17				44003	12.68	45.00
1010	58.57	67.21	3020	61.43	71.67	4167	0.00	0.00	5031	1.41	2.08				B2000	8.45	30.00
1025	15.71	18.03	3021	5.71	6.67	4170	0.00	0.00	5032	8.45	12.50						
1026	12.86	14.75	3024	8.57	10.00	4171	0.00	0.00	5065	0.00	0.00						
1027	17.14	19.67	3026	2.86	3.33	4186	0.00	0.00	5115	0.00	0.00						
			3028	4.29	5.00				5165	7.04	10.42						
			3029	1.43	1.67				5206	1.41	2.08						
			3033	0.00	0.00												
			3034	0.00	0.00												
			3036	1.43	1.67												
			3051	14.29	16.67												
			3052	12.86	15.00												
			3056	0.00	0.00												
			3068	0.00	0.00												
			3132	4.29	5.00												
			3133	1.43	1.67												
			3134	2.86	3.33												
			3135	0.00	0.00												
			3136	15.71	18.33												
			3154	0.00	0.00												
			3176	1.43	1.67												
No. Test	12.86			14.00			82.86			32.00			76.00			72.00	
No of patient seen	70	61		70	60		70	12		70	47		70	17		70	19

* Others 07 - Virology, 09 - Endoscopies, 33 - Diet, 40 - Neuro Lab, 44 - Pulmonary Medicine, B2000 Ophthalmology

Exhibit 3
Number of Tests per Patient per Lab: Med Unit 1, Visist 1

# of Tests patient	Clinical Pathology		Clinical Biochemistry		Microbiology		Radiology		Cardio Function		Others	
	%age all	%age tested	%age all	%age tested	%age all	%age tested	%age all	%age tested	%age all	%age tested	%age all	%age tested
1	1.43	1.64	8.57	10.00	12.86	69.23	50.00	74.47	20.00	82.35	25.71	94.74
2	0.00	0.00	14.29	16.67	2.86	15.38	11.43	17.02	4.29	17.65	1.43	5.26
3	1.43	1.64	12.86	15.00	1.43	7.69	5.71	8.51	0.00	0.00	0.00	0.00
4	5.71	6.56	18.57	21.67	1.43	7.69	0.00	0.00	0.00	0.00	0.00	0.00
5	11.43	13.11	11.43	13.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	17.14	19.67	8.57	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	37.14	42.62	7.14	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	8.57	9.84	1.43	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.43	1.64	2.86	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	2.86	3.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No Test	12.86		14.29		81.43		32.86		75.71		72.86	
Total No. of patient seen	70	61	70	60	70	12	70	47	70	17	70	19
Avg# of Tests / Patient	5.59		3.46		0.29		0.9		0.29		0.29	

* Others: 07 - Virology; 09 - Endoscopies; 33 - Diet; 40 - Neuro Lab; 44 - Pulmonary Medicine; B2000 Ophthalmology

**Exhibit 4
Total Number of Tests per Patient: Visit 1**

# of Tests / Patients	All labs					
	Med Unit - 1		Med Unit - 2		Med Unit - 3	
	% all	% tested	% all	% tested	% all	% tested
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	1.43	1.61	0.00	0.00	1.30	1.14
4	0.00	0.00	0.00	0.00	3.90	3.41
5	2.86	3.23	0.00	0.00	6.49	5.68
6	1.43	1.61	2.38	2.50	15.58	13.64
7	2.86	3.23	0.00	0.00	11.69	10.23
8	2.86	3.23	7.14	7.50	9.09	7.95
9	5.71	6.45	7.14	7.50	15.58	13.64
10	7.14	8.06	7.14	7.50	7.79	6.82
11	11.43	12.90	2.38	2.50	10.39	9.09
12	12.86	14.52	14.29	15.00	10.39	9.09
13	12.86	14.52	7.14	7.50	3.90	3.41
14	7.14	8.06	14.29	15.00	2.60	2.27
15	5.71	6.45	9.52	10.00	0.00	0.00
16	5.71	6.45	7.14	7.50	0.00	0.00
17	2.86	3.23	2.38	2.50	1.30	1.14
18	1.43	1.61	4.76	5.00	0.00	0.00
19	1.43	1.61	2.38	2.50	0.00	0.00
20	0.00	0.00	2.38	2.50	0.00	0.00
21	1.43	1.61	0.00	0.00	0.00	0.00
22	1.43	1.61	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	2.38	2.50	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	2.38	2.50	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00
No Test	11.43		4.76		12.50	
Total #of Patients seen	70	8	42	2	88	11
Avg #of tests/patient	10.8		12.93		7.58	

Med Unit	Visit 1 Avg No of Tests per patient	No of patients seen	Visit 2 No of Lab Tests per patient			
			0	1	2	3
1	11	52	45	3	2	2
2	13	32	28	3	1	
3	8	68	59	2	4	3