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Managerial Study of Medical Oxygen Pipeline System in a Government Hospital with a View to Identify Operational Deficiencies & Develop Improvement Strategies

KEYWORDS: Liquid Oxygen, Medical Gas Pipeline System, Cost variance, Gap Analysis.

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ABSTRACT *Over the last ten years, there has been a significant increase in the use of medical oxygen for treating patients in healthcare facilities, with some hospitals seeing annual increases well in excess of 10%.*

Aim and objectives: Managerial study of the medical oxygen pipeline system in a specialized tertiary care government hospital, with a view to identify operational deficiencies.

Materials and methods: An observational analytical study was performed in the hospital to estimate the consumption pattern with the use of a standardized template. The study assessed the demand consumption variance. A gap analysis was undertaken to identify operational deficiencies.

Observations: An assessment of variation between the consumption of oxygen during the study period and re-filling of the liquid oxygen tank indicated a difference of 5,68,623Ltrs. The estimated loss to the hospital was approx. Rs 14029/- per week. Gap analysis indicated operational deficiencies in infrastructure including the absence of alarms and area monitors, human resource training, documentation and SoP's.

Conclusion: Medical Oxygen supply system is one of the most critical of all services which impacts on patient safety. The focus of the management should align to improving the service and close control of operational parameters.

Introduction
Over the last ten years, there has been a significant increase in the use of medical oxygen for treating patients in healthcare facilities, with some hospitals seeing annual increases well in excess of 10% (1). As per WHO standards, a country should have 3.5 beds per thousand populations, in order to effectively serve its residents. However, the hospital bed density in India was recorded at 0.7 beds per thousand of the population in 2010 (2). Thus, healthcare sector in India offers a huge potential to grow in terms of service facilities as well as healthcare infrastructure. This is one of the major reasons expected to drive the future demand for medical gases in India over the next five years.

Virtually every hospital needs bulk supplies of oxygen and the most economical way to hold a large quantity is in a liquid form (1). Significant advances in therapeutic uses of medical gases have resulted in increased medical gas usage for a number of diverse clinical applications. Hospitals generally have large annual consumption levels of oxygen so bulk liquid is a very cost effective and convenient supply option.

A 500 bedded government tertiary hospital providing cardiothoracic speciality services was located in a metropolitan area. The hospital has a liquid oxygen plant which supplies the inpatient services and critical care areas. Significant costs were expended by the hospital towards liquid oxygen plant. A managerial study for a system or subsystem enables the examination of the system state utilising appropriate tools, identification of operational gaps and recommending improvements for efficiencies/effectiveness of the system.

Aim
Managerial study of the medical oxygen pipeline system in a specialized tertiary care government hospital, with a view to identify operational deficiencies through a gap analysis and propose improvements for the oxygen management in the hospital.

Objectives.
The objectives of the study included

- To estimate the consumption and demand patterns of oxygen in the hospital
- System study to identify operational deficiencies
- Undertake a Gap Analysis and identify the causes leading to variation in management operations of oxygen system.
- Formulate suitable set of recommendations in light of observations.

Materials and Methods
An observational study design was undertaken in the hospital. The observational management study was undertaken for the system infrastructure, utilisation study, human resource and operational controls. The study was performed in all wards, where oxygen outlet exists through manifold gas pipeline system (MPGS). The study was conducted from19th Feb 2015 to 26th Feb 2015. All the inpatients admitted in the hospital formed the study population. A total of 11 wards of the hospital were included in study setting.

The data for calculation of oxygen consumption during the study period was calculated by perusal of documents, direct observation and actual consumption at the user end. The documents perused included entries of liquid oxygen filling at the liquid oxygen plant & standardised guidelines by National Health Services (NHS) Hospital Technical Manual (HTM – 02) on the subject. Direct observation was undertaken for the filling of liquid oxygen tank by vacuum insulated transportation tank (VITT).

A standardised template was developed for calculation of oxygen consumption at user end, after a focused group interview. The front line workers were trained regarding the template and calculation of oxygen consumption at user end. The actual recording of the data was undertaken by the frontline workers after training and observational trail frame work with validation of the same. The oxygen consumption template included the details of the patient, ward, diagnosis, total time of oxygen consumption, rate of oxygen in litr/min and total consumption in litres.

Observation & Discussion
1. System Infrastructure (3)
Oxygen Plant & Supply System. The oxygen supply system in the hospital constitutes liquid oxygen plant, oxygen cylinder manifold backup system, network of distribution pipes and end point outlets in the wards. The main source of the oxygen supply is the liquid oxygen plant.

The Liquid oxygen plant of the hospital was installed in 2007 by BOC India Ltd at the cost of 103 Lakhs for MPGS system and liquid oxygen plant. The capacity of liquid oxygen plant in the study hospital is 867 ltrs of liquid oxygen. There are three main parts in the liquid oxygen plant in the study hospital

- Vacuum Insulated Evaporator (VIE) -The storage vessel for liquid oxygen is known as a vacuum insulated evaporator (VIE). A VIE is an expensive piece of equipment and is only used in very high demand areas e.g. large hospitals. One litre of liquid oxygen supplies 842 litres of gaseous oxygen at 15° C and normal atmospheric pressure.
- Vaporiser-The vaporiser is aluminium based coil which converts liquid oxygen in the gaseous form. The maximum conversion can be up to 1000 ltr / hour. However the size and number of vaporizer is according to consumption of liquid oxygen in the hospital.
- ONED (Operation and Engineering Device) - After the vaporiser the gaseous oxygen enters the ONED. Here the pressure is titrated to 4.5 bar as recommended by HTM guidelines.

The source of supply of liquid oxygen to the main tank of the liquid oxygen plant is by Vacuum Insulated Transportation Tank (VITT), which is sent by the company on alternate days.

The hospital also caters to an Oxygen cylinder backup system. The capacity and number of cylinders in the manifold room is 40 cylinders X 7000 ltrs. Besides a second back up is available in all critical areas through varied capacity cylinders; 4 cylinders x 7000 ltrs in Operation theatre, 4 cylinders x 7000 ltrs& 3 cylinders x 1246 ltrs in Surgical ICU, 3 cylinders x 1246 ltrs in Respiratory ICU, 3 cylinders x 1246 ltrs in Cardiac ICU, 3 cylinders x 1246 ltrs in Accident & Emergency and 3 cylinders x 1246 ltrs in Cardiac Cath Lab. The first and second back up system in manifold and wards was manual and require physical changing of the controls for the manifold.

The Distribution System for oxygen consists of pipes which are colour coded. The Oxygen carrying pipes are coded with a white band on yellow canary background. As per literature an area alarm system is required for the systems however we observed that there is no area alarm system present in the MPGS system of the study hospital except in the OT and Surgical ICU. Further the area control panel and distribution boxes are present only in the operational theatre and Surgical ICU of the study hospital.

In the end point system the number of Oxygen outlets available in various areas of the hospital included; CCU – 08, CCL – 06, Surgical ICU – 32, Q Ward – 22, Female Ward – 3, Private Ward – 2, Respiratory ICU – 18, Accident & Emergency – 03, Radio-diagnosis – 02 and Operation Theatre – 16. The alarm systems were observed to be present only in operation theatre and surgical ICU. The alarm gave a visual as well as audio alert when the volume and pressure in the pipeline system falls below a defined pressure point. Similarly control panel were present only in operation theatre in surgical ICU. No control panels were present in the wards.

2. Consumption/Utilisation
Consumption of Oxygen. The study on consumption of oxygen was under taken as per the standardised template by the healthcare workers in the hospital. The study carried over 08 days indicated that the oxygen consumption in the hospital varied from 52,650 ltrs to 82,860 ltrs per day during the period of study. The average consumption was calculated at 76,168 ltrs per / day. During the study period on average 359 patients were admitted in the hospital. The consumption of oxygen per patient / day was an estimated 212 ltrs for the hospital. The detailed observations are given in Table No 1.

Table No 1: Consumption Pattern of Oxygen in Litres

S No	Ward	19/2	20/2	21/2	22/2	23/2	24/2	25/2	26/2
1	A&E	420	60	Nil	Nil	Nil	Nil	200	80
2	ICCU	5220	5760	4740	5880	6060	1260	225	10580
3	CCL	180	320	150	Nil	2225	200	Nil	450
4	Q Ward	8160	12240	19440	12990	13485	5040	12000	16380
5	Surgical ICU	58140	47700	32790	30180	27550	28385	37530	43200
6	Female Ward	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
7	Pvt Ward	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
8	Resp ICU	8820	8892	7830	3600	5760	14400	12840	8010
9	X-Ray	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
10	OT-01	1040	750	Nil	Nil	2660	3660	320	2195
11	OT-02	880	940	Nil	Nil	Nil	480	Nil	1080
	Oxygen consumption	82,860	76,662	64,950	52,650	57,740	53,425	63,115	81,975
	Patient Admitted	327	329	316	318	300	312	312	301

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Re-filling of the Oxygen in Plant. As detailed the study hospital has 867 Ltrs capacity liquid oxygen tank with 1 litre of liquid oxygen supplying 842 litres of gaseous oxygen at 15° C and normal atmospheric pressure. The supply of liquid oxygen is undertaken on an annual rate contract through an outsourced firm. The filling of oxygen tank was being undertaken every 48 Hours. This was based on the consumption of oxygen in the hospital. A total of 4 observations were made during the study period. The average liquid filled (in m^3 of gas equivalent) was observed to be 275.5 m^3 of gas equivalent. The Table 2 below gives detail of re-filling of oxygen in the oxygen tank.

Table No 2 :Re-filling of the Oxygen in Liquid Oxygen Tank

Sr No	Date	Total liquid Filled (In M^3 of gas Equivalent)
1	19/2/15	315
2	21/2/15	315
3	23/2/15	210
4	25/2/15	262

Variation in Consumption and re-filling. An assessment of variation between the consumption during the study period and re-filling of the liquid oxygen tank indicated a difference of 5,68,623Ltrs.

- Amount of liquid gas filled m VIE (in Ltrs) : 1,102,000
- Amount of consumption at the user end (in Ltrs) : 5,33,377
- Variation in consumption and re-filling : 5,68,623

Cost of Variances. The contracted cost of liquid oxygen is Rs 24.67 per m^3 (1000 Ltrs). Accordingly the cost of the variance in the study hospital was observed to be Rs 14,027.29/ week. Extrapolated to over one year period the cost variance will amount to over Rs 7.29 Lakhs. From a managerial perspective these losses are required to be investigated for operational deficiencies and issues.

3. Human Resources.

The medical gas pipeline system is manned by hospital staff at the liquid oxygen plant. No induction training was provided to the staff in managing the system. There are no formal documented handovers of the system on change of staff. Staff for repair and maintenance is provided by the engineering department through outsourced contract. During the period of study, it was observed that staff was not present through the working hours.

4. Operation Controls

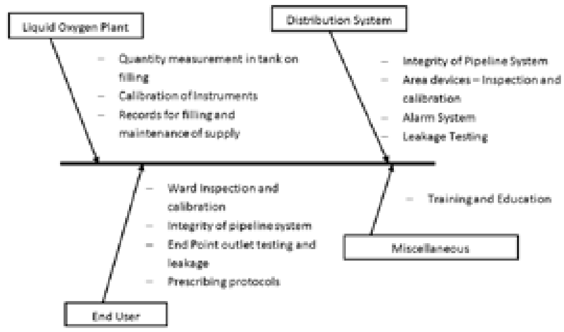
No formal guidelines, standard operating procedures are available for the medical oxygen system. In the absence of formal SOP's the resulting work practices were unpredictable or absent. Preventive maintenance programmes were absent. Formal monitoring and documentation for operations are not in place and no checklists available. The outsourced staff was called after the loss of revenue was noticed. A test audit was conducted through the staff and 5 sites were identified where leakage of gases was occurring which was highlighted above in the gap between consumption and demand.

Gap Analysis

In management literature, gap analysis involves the comparison of actual performance with potential or desired performance (4). Gap analysis identifies gaps between the optimized allocation and integration of the inputs (resources), and the current allocation-level. This may reveal areas that can be improved.

To understand the operational deficiencies and issues, a gap analysis was undertaken at three levels; the liquid oxygen plant, the distribution system & end use areas. The gap analysis focused on structural, process and operational issues in the respective sub-system.

FIGURE 1: GAP ANALYSIS PARAMETERS



The figure above details the various parameters undertaken to understand the gaps in the management of the medical gas supply system in the hospital. The observations revealed gaps at various stages which were one of the many contributory causes to the variations noticed in the consumption and filling of oxygen gases.

At the liquid oxygen plant the hospital relied on the instruments from outsourced company to measure the quantum of gases. The gauges on the liquid oxygen plant were not calibrated and the staff in charge of the plant was not trained in the liquid oxygen plant system. Limited documentation was present for the receipt of the gas and quantum filled but no documentation on the maintenance and calibration of plant were available.

The distribution system revealed major gaps. At the foremost was the system which is manual and requires human interface to change over from one sub system to other. Absence of area monitors and controls in the hospital is a major gap. Failures in supply thus cannot be detected in time and any leakages also cannot be controlled. Alarm system was available only in OT and Surgical ICU. As a result of which the nursing staff had to periodically check the systems leading to fatigue and duplication of work. No records were found for testing of the pipeline system. Documentation for the maintenance of the pipeline system were not available.

At the end user prescribing protocols were available as per standard treatment guidelines. However as for the distribution system there was an absence in maintenance & leakage testing. Documentation was not available and no staff training had been undertaken. The summarised table of the observations and gaps found in the study are given in Table 3.

TABLE 3: GAP ANALYSIS

S No	Parameter studied	Observation	Gap
Liquid Oxygen Plant			
1	Quantity measurement in tank on filling	Through suppliers readings & gauge	Internal processes require to be defined

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S No	Parameter studied	Observation	Gap
2	Calibration of instruments	No records available	Confidence in instruments accuracy is questionable
3	Stock levels	Readings through plant gauge	Appears to be appropriate.
4	Documentation	Only filling details. No maintenance records	Inadequate documentation processes
Distribution System			
5	Integrity of Pipeline System	No testing records	Leakages may be present
6	Area devices	Present in OT & Surgical ICU	Area devices in many other areas not present
7	Inspection and calibration	No records	Inadequate documentation processes
8	Alarm System	Present in ICU & Surgical ICU	Not present in many clinical areas, can compromise patient safety
9	Leakage Testing	No Testing details available	Inadequate maintenance protocols
End user System			
10	Ward Inspection and calibration	No inspections in last 1 year	Inadequate maintenance & inspections
11	Integrity of pipeline system	No records of tests	Likelihood of leakages
12	End Point outlet testing and leakage	Not available	Patient Safety can be compromised
13	Prescribing protocols	Available as per standard treatment guidelines	
Operations &Misc			
14	Training and Education	No formal training carried out for staff	Inadequately trained staff
15	Audits	No inspection audit reports available	Deficient management & control processes
16	Documentation & Checklists	No Checklists and documentation available	Deficient management & control processes

Recommendations

Fundamentally the strategies to be adopted to undertake quality improvement measures for the management of the medical oxygen system include; formulation of Standard Operating Procedures (SOP), developing and implementing a maintenance and repair programme, training of staff, SOP for inspections, effective management of rate contract for oxygen supply, outsourcing the pipeline maintenance in case expertise is not available.

Documentations and SOP's are very important to developing quality improvement programme. SOP specifies the methods by which the tasks will be undertaken. The SOP may also lay down standards for adherence, against which the performance is measured.

A repair and maintenance programme is mandatory for a critical service like Oxygen supply system. In case suitable expertise is not available the same can be outsourced to a technically competent firm. The maintenance programme should have defined daily, weekly, monthly and yearly tasks. The tasks and periodicity should be clearly specified. An example of daily task routine is given in Table 4 below.

TABLE NO 4: DAILY TASKS

S No	Daily – general tasks	Checked	Not-checked
1	Check all alarm panels, manifolds and plant visual indicators for correct function, absent displays or damage		
2	If any manifold is observed to be in operation on its "emergency reserve" bank, replacements for the empty cylinders should be made available immediately		
3	Check all plant and manifold pressure gauges for abnormal conditions		
4	Check all plant and manifolds for unusual noises, signs of overheating, vibration etc		

Staff should be deployed in the system with clear lines of authority and responsibility. It is recommended to educate and train the front line workers in operational maintenance. Any new staff should have a period of induction training.

Effective management of rate contract by assessing operational stocks and predicting average daily demand through scientific inventory management techniques is important to help improve quality. It is important to assess the operational stock and the primary reserve stock for the gas supply system (5). As an illustration in our study hospital example we will calculated the same as

Operational Stock: The operational stock is based on average daily demand predicted for the end of the contract period and calculated by

Operational Stock = Average Daily Demand x Agreed Delivery Period Average Daily Demand = 5,33,377ltrs/08 days = 66,672.12 Ltrs

Operational Stock = Average Daily Demand x Agreed Delivery Period.

Average Daily Demand = 5 , 3 3 , 3 7 7 l t r s / 0 8 days = 66,672.12 Ltrs

Operational Stock = 66,672.12 x 2 (since supply of oxygen is alternate day) = 1, 33,344.25 Ltrs

Calculation of Primary reserve stock: The matrix table for the calculation of primary reserve stock based upon distance from gas supplier and fitting of telemetry is utilised for the purpose. In the study hospital the distance of gas supply depot is less than 75 km. There is no telemetry installed in the VIE. Hence, reserve stock = 66,672.12 x 5 = 3, 33,360.6 Ltrs

Total Stock. The total stock held by the hospital should be

Operational + Primary Reserve stock = 1,33,344.25 + 3,33,360.6 = 4,66,705 ltrs. So, the VIE in the Study Hosp should have 4,66,705Ltrs of Oxygen at any given point of time.

A telemetry device in VIE may be considered which will enable the contracted company to monitor pressure as well as volume of VIE. The re-filling of VIE can be done on real time basis.

Management should exercise close control and call for records and documentation regularly. Inspections should be

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undertaken. A commitment of the management is a must since the service impacts on patient safety.

Conclusion

As technology leaps forward and hospitals perform increasingly sophisticated procedures, there is a need to develop the management processes to deliver quality services. Medical Oxygen supply system is one of the most critical of all services which impacts on patient safety. The focus of the management should align to improving the service in a cost effective manner and close control of operational parameters.

The study highlights that in Indian hospitals there are operational management deficiencies which require to be addressed. Training of staff, developing standards, having a good maintenance programme, effective inventory management and inspections will address these deficiencies and help the hospitals in improving quality and patient safety.

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