Evaluating the impact of additional clinical resources to manage the winter surge in demand for emergency paediatric intensive care retrieval

Christina Pagel[1], Daniel Lutman[2], Eithne Polke[2], Samiran Ray[2], Padmanabhan Ramnarayan[2]

1. Clinical Operational Research Unit, University College London, 4 Taviton Street, London, WC1H 0BT

2. Children's Acute Transport Service (CATS), Great Ormond Street Hospital NHS Foundation Trust, 26-27, Boswell Street, London, WC1N 3JZ, UK

Academic degrees:

Christina Pagel – BA, MSc, MSc, PhD

Daniel Lutman –

Eithne Polke –

Samiran Ray –

Padmanabhan Ramnarayan –

Corresponding author: Christina Pagel (c.pagel@ucl.ac.uk)

ABSTRACT

We evaluate whether providing extra clinical resource during the winter of 2014/15 improved the availability of retrieval teams in a North London retrieval service. We explored the potential impact of different staffing patterns in future years to inform service planning.

We used retrospective routine data to compare the proportion of referrals refused due to lack of capacity between the winter of 2014/15 and the previous five winters. In the winter of 2014/15, an additional team were on shift for 12% of the time. We compared shifts where the additional team were available in the winter of 2014/15 to similar shifts in previous years. We used mathematical modelling to predict the potential impact of staffing levels in future winters.

From 1/11/14 to 31/1/15, the service performed 380 emergency retrievals and refused 25 due to no available team (6.2%). The proportion of refusals during shifts with the additional team available in 2014/15 was 4.2% vs 12.4% in similar shifts from 2009/10 to 2013/14 (p=0.026).

Mathematical modelling showed that staffing an additional team the whole time could result in 2% of referrals refused compared to 8% without and that much benefit could be obtained by a third team working a 12 hour shift from 10am-10pm (refusal rate 2.8%).

KEY POINTS

Providing even limited extra capacity during winter can significantly reduce the referral refusal rate.

Almost all the benefit of staffing an additional team for 24 hours a day can be achieved by staffing an additional team for 12 hours a day from 10am-10pm.

Simple mathematical modelling can be very useful in predicting the potential impact of staffing decisions in the future.

Background

Paediatric intensive care units (PICU) in the UK have been extensively centralised over the past two decades. As a result, half of all emergency admissions to PICU are children who have been transported from other hospitals. The overwhelming majority of such transports are performed by specialist PIC retrieval teams who take the expertise of a PICU to the patient at a remote hospital. The use of such specialist teams has been shown to improve PICU survival (Ramnarayan et al., 2010).

Timely arrival of the retrieval team at the patient bedside and initiation of PICU care has been considered an important clinical performance marker (Ramnarayan, 2009). UK Paediatric Intensive Care Standards specify that retrieval teams should aim to reach the patient bedside within 3 hours of accepting the transport (4 hours for geographically remote areas) ("Paediatric Intensive Care Society - Standards 2008 - PICS_standards.pdf,"). Lack of specialist teams to undertake retrieval may worsen outcomes for critically ill children, either because children then require transport by non-specialist teams or because children spend longer in local hospitals that are not equipped with a full range of specialist PIC services. Availability of retrieval teams can be particularly restricted during winter periods: referrals of infants with acute respiratory failure approximately double during this period and almost all these infants are admitted to PICU following retrieval from district general hospitals (O'Donnell et al., 2010), stretching a system that is already running at high bed occupancy levels (Hanratty and Robinson, 1999; Pearson et al., 2012). This surge in demand regularly outstrips availability of teams and results in an increase in the refusal rate, delays in getting a specialist team to the patient, and extends the time before the child reaches definitive care in the PICU.

Plans for surge management have been published recently by the Paediatric Intensive Care Society (PICS) and NHS England ("Paediatric Intensive Care Surge Report," 2014). They identify the winter surge as lasting an average of 6 weeks between mid-November and January, and recommend various measures during this time, such as increasing capacity, streamlining work processes and rescheduling elective workload. However, the potential impact of adopting any of these measures on availability of retrieval teams or timely arrival of the team at the patient bedside has not been formally assessed. In addition, there is little evidence to guide what the best and most efficient service model is to achieve these targets.

For this paper, we performed retrospective analysis of routinely collected data at a busy regional PIC retrieval service based in London (Children's Acute Transport Service, CATS) to evaluate whether providing extra clinical resource over a 3-month period during the winter of 2014/15 actually did improve the availability of retrieval teams and time to bedside. We then use mathematical modelling to consider the potential impact of such extra resource in future winters and investigate how this impact could be maximised.

Methods

Setting

The analysis was conducted at CATS, the busiest PICU retrieval service in the UK. The service has two full time retrieval teams, transporting patients from over 50 district general hospitals covering a large geographical region in the South East of England to tertiary intensive care units in London. CATS perform around 1100 emergency retrievals annually, a large proportion (30%) of which are carried out in a 3-month winter period between November and January. Before 2014, only two retrieval teams were available throughout the year, leading to an inevitable increase in both the number of referrals refused (lack of available team) and an increase in time to bedside for the patient during the winter months. Over a 3-month period during the winter of 2014/15, additional resources were commissioned to create a third specialist team to work an additional 8 hour shift, with the expectation that this extra capacity would reduce both the number of referrals refused and the time a child waited at a local hospital for the specialist team to arrive.

Data

Since 2009, data on all CATS referrals are checked and entered onto a dedicated database daily. Information recorded includes referral outcome, reason for refusal if the referral was refused and the time course of teams during each retrieval. We examined time taken to reach patient bedside from referral acceptance and refusals due to no available team.

The additional retrieval team was deployed from 1 November 2014 to 31 January 2015, between 2pm and 10pm on weekdays (excluding a 2 week period over Christmas). Since demand for retrieval is not constant throughout the 24 hour day, the time of day needs to be taken into account when comparing outcomes between periods when two or three teams were on duty. Thus, in all our analysis we perform two sets of comparisons:

1. Comparing overall outcomes in the winter of 2014/5 to overall outcomes of the winters for each year since the 2009/10 winter (1 November to 31 January);
2. Only comparing outcomes for shifts when the third team were on duty in the winter of 2014/15 to the outcomes of the same number of similar shifts in previous winters.

It was not possible to use exactly the same dates each winter for comparison option 2 because weekends and public holidays (25th, 26th December and 1st January) fell on different days of the week each year.

Descriptive analysis

We present the raw numbers for total number of referrals, demand for PIC retrieval and refusals for each winter from 2009/10 to 2014/15 and analyse the distribution of demand over the 24-hour day. We also describe the actual activity during times with three staffed teams in the winter of 2014/15.

Analysis of refusals

Since referrals to CATS can be refused for several reasons other than lack of availability of a PIC retrieval team, we counted refusals only where no CATS team was available, since this the only sort of refusal that the presence of the additional team could be expected to influence. Since the absolute level of demand for retrieval varies from winter to winter (and thus the absolute numbers of refusals), the outcome of interest was the proportion of true demand for emergency transfer that was refused because no team was available.

The proportion of refusals over the winter period was defined as the number of refusals divided by the true demand, where the true demand is simply the sum of all emergency retrievals performed by the team and refusals due to no CATS team being available. Elective transports were not included in this calculation of "true demand".

The overall proportion of true demand that was refused in the winter of 2014/5 was compared to the average proportion of refusals over the previous 5 winters using an exact one-sided Binomial test. A one-sided test was used since the impact of the additional team could only be to reduce refusals (there is no plausible mechanism whereby an additional team could lead to more refusals).

However, the third team was only active for 8 hours on any given day and demand is not constant throughout the 24 hour day. Therefore, a fairer evaluation of its impact is to compare the overall proportion of refusals while the third team was actually on shift in 2014 to the average proportion of refusals over the same number of similar shifts in the previous 5 years. The significance of any difference was again evaluated using the exact one-sided binomial test.

Response time

One important measure potentially relating to patient outcome is the time to the patient's bedside for a retrieval team once a referral has been accepted. This is the sum of the waiting and mobilisation times (i.e. time from referral acceptance to team leaving the base) and the time taken to journey from CATS to the patient's hospital (see figure 1). In practice, the "waiting time" is zero if a team is already in the office and mobilisation times are typically short (about 15 minutes). The largest variability is in waiting times when a team is not immediately available and the journey time to the remote hospital (which depends on traffic and the hospital's location).

The only factor that we expect the additional team to influence is the waiting time from a referral being accepted to a team being available to go on retrieval. Thus, we compared the mean waiting time for shifts with three teams in the winter of 2014/5 to the mean waiting time for the same number of similar shifts over the previous 5 years, performing a one sided t-test for significant difference in the means. To examine the frequency of particularly long waits for a team, we also compared the proportion of retrievals performed with a wait time of over 4 hours between shifts with 3 teams in 2014/5 and the same shifts with 2 teams in previous years, using a one-sided Fisher's exact test for significance. The clinical importance of reducing waiting time is in getting teams to the child's bedside as soon as possible after the referral has been accepted. Thus, we also compared the mean time to bedside for shifts with three teams in the winter of 2014/5 to the same number of similar shifts over the previous 5 years, performing a one sided t-test for significant difference in the means. All tests are one-sided since there is no plausible mechanism for an additional team to increase either the waiting time or the time to bedside.

Potential impact of an additional team in future years

We applied a mathematical modelling approach called queuing theory to analyse demand and capacity over the winter period. Queuing theory considers the balance between demand (new referrals), capacity (number of teams on shift) and average time out of the CATS office for a retrieval team ("service time") and is often used in the context of emergency health care (Barton, 1986; Haghighinejad et al., 2016; Liu et al., 2016). We modelled the CATS service as a "multi-server loss queue". The average observed service time was 5.4 hours and there was very little variation between years.

Applying this approach allowed us to estimate the proportion of refusals *expected on average* when either 2 teams or 3 teams are on shift and, crucially, allowed us to explore these four hypothetical questions:

1. What would have happened if the third team had not been available this winter?
2. What would have happened if the third team had been available 24/7 this winter?
3. What would happen in an “average” winter with only 2 teams available throughout?
4. What would happen in an “average” winter if the third team were available 24/7?

Timing of an additional team if not available 24/7but only for a part-day shift

In the winter of 2014/15, when working, the third team was active for an eight hour shift from 2-10pm on weekdays. This shift pattern was chosen by the CATS clinical and management team based on experience of previous winter but was not based on detailed data analysis or mathematical modelling. We developed a mathematical simulation model (see e.g. (Goldberg et al., 1990; Mathews and Long, 2015) to simulate the proportion of refusals over a winter with an additional team shift every day to inform future decisions about timing and duration of a third team shift. We investigated 8, 10 and 12 hour shifts starting every hour from midnight to 11pm and looked for the shift pattern that minimised the proportion of demand refused.

For each combination of shift duration and shift start time, we simulated emergency referrals and team availability by hour from 1 November to 31 January. Referrals were sampled using a Poisson distribution with means taken from observed hourly average referrals (see Figure 2). The time taken for a simulated retrieval was sampled from an exponential distribution with mean taken from observed overall average out of office time (see results section). We ran 200 simulations for each scenario and plotted the average overall refusal rate (average over 200 simulations) against start time of shift for each hypothetical shift duration.

Results

Descriptive Analysis

In the winter of 2014/15, the additional team were intended to be on shift from 2pm-10pm, Monday to Friday (excluding a 2 week period over Christmas). In fact, they were not available as often as planned due to difficulty filling the post on an ad hoc basis. In all, a fully staffed additional team was available from 2-10pm on 34 out of 62 working days over this period, covering just over 12% of total time between 1 November and 31 January.

The total number of calls, demand for emergency retrieval, refusals due to lack of team and number of emergency retrievals for each winter from 2009/10 to 2014/15 are shown in table 1, along with the observed proportion of demand that was refused.

The demand during the winter of 2014/15 was the highest to date but the number of refusals and the proportion of refusals were lower than all previous years except the winter 2009/10 which had much lower demand.

The pattern of demand over the 24 hour day is shown as an average for the 2009/10 – 2013/14 winters and the winter of 2014/15 in Figure 2. We calculated average demand per hour so that, for instance, in 2014/15, the average demand for emergency referrals (measured at time of referral) between 10 and 11am was 0.28 per hour (equivalent to 6.7 per day).

Demand is highest between 10am and about 8pm and there is a clear difference between daytime and night-time level of referral.

Analysis of impact on refusals

The overall average proportion of refusals from 2009/10 to 2013/14 was 7.9%. In the winter of 2014/15, the additional team were on shift for only 12% of the total time period and for 17% of the total demand. Thus, we would not expect to see an enormous impact on *overall* refusal rate in 2014/15. Treating 7.9% as the baseline proportion of refusals in winter, the probability of observing a proportion of refusals of 6.2% or less in 2014/15 is 11% (i.e. p=0.11).

Table 2 gives the total number of calls, demand for emergency retrieval, refusals due to lack of team and number of emergency retrievals for each winter for shifts where the additional team was active (2014/15) and the same number of similar shifts in previous years from 2009/10 to 2013/14.

The average proportion of refusals for these shifts between 2009/10 and 2013/14 when there were only two teams available was 12.4%. In 2014/15, we observed that the proportion of refusals was 4.5% during the shifts when an additional team was available. Treating 12.4% as the baseline proportion of refusals, the probability of observing a proportion of refusals of 4.5% or less in 2014/15 is 2.6% (i.e. p=0.026). This provides strong evidence that the additional team did reduce the proportion of demand that was refused.

Waiting time and time to bedside

Table 3 shows the comparison between this winter and the previous 5 winters in terms of the average waiting time and average total time to bedside. Only shifts where the additional team were available in the winter of 2014/15 were compared to similar shifts in previous years.

It is clear that the third team had a major impact on the waiting time to mobilisation, almost halving it. This reduction in waiting time led to a significant decrease in overall mean time to bedside (by about 45 minutes).

The overall proportion of transfers where waiting time was longer than 4 hours during shifts where the additional team was available in 2014/15 was 1.6% compared to 10.6% for similar shifts in previous years (p=0.01). The impact of the additional team was to reduce in particular the likelihood of having to wait a very long time for a team to become available again.

Potential impact of additional team in future years – application of queuing theory

The overall mean demand during the winters 2009/10 – 2013/14 was 0.164 retrievals per hour. With two teams available throughout, the expected proportion of demand that is refused from the queuing model is 7.2% which is consistent with the average observed proportion of refusals of 7.9%. The results from queuing theory are summarised in table 4.

The agreement between theory and observation is very good and provides confidence in the application of the queuing model to the hypothetical scenarios proposed above in the methods section.

The expected outcomes for the four hypothetical scenarios using queuing theory are given in table 5. Note that the overall level of demand is set to that observed in each time period. Thus, we estimate that if no additional team had been available at all this winter, there would have been around 36 refusals instead of the 25 observed and, further, if the additional team had been available every day around the clock, there would only have been 8 refusals overall. However, this winter was an unusually difficult winter with very high demand. In an "average" winter, staffing a third team the whole time would reduce expected refusals from around 27 to between 5 and 6.

Timing of an additional team if not available 24/7but only for a part-day shift

We first tested our simulation against the observed overall proportion of refusals in the winter of 2014/15 by incorporating the hours when a third team was available in the simulation to match those actually worked (Table 6). Referral rates were simulated from 2014/15 average hourly demand by month.

The agreement between the simulation and what was actually observed is very close, giving confidence that our simulation model is fit for purpose. The median refusal rate over the simulations was 6.5% with an interquartile range [5.6%-7.5%].

The average proportion of refusals over 200 simulations for an extra shift each day by start time of shift and duration of shift is shown in figure 3. For these runs, referral rates were simulated from 2009/10-2014/15 average hourly demand by month to represent a future “average” winter. The red line shows the average refusal when only 2 teams are available (8.0%, comparing well to observed average refusal rate 2009/10-2013/14 for 2 teams of 7.9%), corresponding to a “worst case”. The green line shows the average refusal rate if 3 teams were available 24 hours a day corresponding to a “best case” (2.0%). We note the simulation estimate for 3 teams is higher than that from queuing theory, which is likely due to fact that we could take time-varying demand into account in the simulation. The blue, purple and black lines respectively show proportion of refusals for 8, 10 and 12 hour shifts starting at each hour of the day.

Unsurprisingly, the best results are obtained when teams are active during the day (particularly the afternoon) when referral rate is highest (see figure 2).

The best option would be a 12 hour shift starting at 10am, which would see on average just under 3% of demand refused due to no available team. However, refusals rates are still low (around 3%) for a10 hour shift starting at 11am. There is reasonable benefit conferred going from an 8 to a 10 or 12 hour shift since we can then cover the whole of the busier period which runs approximately from 10am to 9pm. Given an 8 hour shift, the lowest refusal rates (around 4%) are seen for a shift starting any time between 11am and 1pm with 10am and 2pm also reasonable options. Thus, the shift time chosen by the team was close to optimal. Note that the refusal rate of 4% for an 8 hour shift is lower than that observed in the winter 2014/15 since the third team did not work every day.

It is also important to note that staffing a third team for only half the time in a 12 hour shift compared to 24 hours a day achieves almost all the benefit of having extra resource (a refusal rate of 2.8% vs 2.1%) and even an 8 hour shift achieves over two thirds of the benefit for only one third of the time.

Limitations

We have made a number of simplifying assumptions in this analysis. In using the exact binomial test for the proportion of refusals we assume that the refusal rate does not depend on the absolute level of demand, which is not realistic. A similar limitation holds for our test of the proportion of retrievals with longer wait time. However, given that 2014/15 was the busiest year to date, this would only make our tests more conservative and so our conclusion of a significant impact during additional team shifts remains valid. The matching between additional team shifts worked in 2014/15 and equivalent shifts in previous years is not perfect. We cannot simply use exactly the same dates since referrals tend to be lower at weekends. Thus there is some level of arbitrary decision making involved in deciding how to allocate the working days with no third team this winter to previous years' working days. We kept to the same number of overall shifts per month for each year for the similar shift allocation, but a choice of different days might have to slightly different results as observed demand (and refusals) vary day by day. That said, we performed a simple sensitivity analysis by choosing different days in previous years (but keeping to the same overall number of shifts) and in all cases the proportion of refusals in 2014/15 was significantly lower.

Discussion

Although an additional CATS retrieval team was available for only 12% of the time between 1 November and 31 January 2014/15, representing 17% of the total demand for emergency retrieval, it did have an impact on both proportion of refusals and time to bedside when compared to previous years. In particular, mean waiting time was almost halved (from 90 to 45 minutes) when an additional team was available and the proportion of times there was a wait of over 4 hours for a team fell dramatically from over 10% to 1.6%.

The potential impact in future years in terms of reductions in refusals and time to bedside are potentially quite large, but they come at the added cost of an additional team and more idle time in the office for each retrieval team. Our simulation modelling has shown that most of the benefit could be achieved by an additional daily 12 hour shift and could inform the timing of a third shift in a future winters (whatever the duration). For shifts between 8-12 hours long the best start time is between 10am and 12pm.

To know whether the additional cost makes economic sense we would need to be able to set a price on each refusal averted and to understand better the impact that waiting for a team has on the child in the remote hospital (e.g. worsening clinical outcomes, staff time spend in the local hospital caring for the child). These are complex questions with (currently) unknown answers that would require a dedicated research project to address.

Providing extra capacity and coping with the winter surge is an acknowledged problem in a resource-constrained health system. Often, responses and coping strategies are hospital and context-specific and might also change from year to year. They are rarely carefully evaluated using retrospective data and if they are, such evaluations are rarely published, stifling the opportunity for hospitals or services to learn from each other. Although this was a relatively small intervention in a single retrieval service, we hope that this report stimulates and aids discussion on how to plan more effectively for the winter surge in future years. We also hope it shows the useful information that can be generated using some relatively simple mathematical modelling methods.

Competing Interests

The authors declare that they have no competing interests.

Author contributions

CP and PR conceived of the study. CP designed and carried out the evaluation and mathematical modelling and wrote the first draft of the paper. DL, EP and PR planned and set up the additional third team resource in the winter of 2014/15 with funding from the service commissioners and contribute to maintaining the dataset used for this work. DL, EP, SR and PR advised on outcomes of interest to evaluate and future staffing options to explore. All authors read, commented and contributed to the final draft.

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Tables

Table 1 Descriptive analysis of activity for winters 2009/10 to 2014/15.

1 Nov - 31 Jan	All calls	Total demand for emergency retrieval	Total refusals because no team available	Total number of emergency retrievals	Proportion of refusals
2009-10	685	328	18	310	5.5%
2010-11	717	364	27	337	7.4%
2011-12	689	372	30	342	8.1%
2012-13	683	360	36	324	10.0%
2013-14	726	390	34	356	8.7%
2014-15	734	405	25	380	6.2%

Table 2 - refusals and demand for emergency retrieval for each year only during the shifts the third team were available for in 2014/15 and similar shifts in previous year.

1 Nov - 31 Jan	All calls	Total demand for emergency retrieval	Total refusals because no team available	Total number of emergency retrievals	Proportion refusals
2009-10	125	66	11	55	16.7%
2010-11	131	73	9	64	12.3%
2011-12	122	63	7	56	11.1%
2012-13	91	50	4	46	8.0%
2013-14	115	68	15	53	22.1%
2014-15	126	67	3	64	4.5%

Table 3 - comparison of mean waiting time to mobilisation and mean time to bedside for shifts that the additional team were available in 2014/15 and similar shifts in previous winters.

Time period	Mean **waiting time** (hours)	Standard error
Additional team shifts 2014/15	0.768	0.168
Similar shifts 2009/10 - 2013/14	1.50	0.173
(one way) p-value of difference = 0.02		
Time period	Mean **time to bedside** (hours)	Standard error
Additional team shifts 2014/15	2.10	0.190
Similar shifts shifts 2009/10 - 2013/14	2.86	0.178
(one way) p-value of difference = 0.02		

Table 4 - queuing theory applied to the demand during shifts where the additional team were available in 2014/15 and similar shifts in previous years

Winter	Expected proportion of refusals from queuing theory	Observed proportion of refusals
2009/10 – 2013/14 – two teams available (additional team type shifts only)	14.3%	12.4%
2014/15 – three teams available (additional team type shifts only)	4.6%	4.5%

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Table 5 - using queuing theory to estimate potential impact of different levels of service provision.

Scenario (hypothetical scenario)	Total demand	Expected proportion of refusals	Expected number of refusals
1. No third team available for winter 2014/15	405	9.0%	36
2. Three teams available for all of winter 2014/15 (24/7)	405	2.0%	8
3. Two teams available for an average winter (mean demand over all years)	363	7.4%	27
4. Three teams available for an average winter (24/7)	363	1.5%	5.5

Table 6 – comparison of simulation vs what actually happened in the winter of 2014/15.

1 Nov - 31 Jan	Total demand for emergency retrieval	Total refusals because no team available	Total number of emergency retrievals	Proportion of refusals
2014-15	405	25	380	6.2%
2014-15 SIMULATION MEAN	403	26	377	6.5%

Figure Legends

Figure 1 - illustration of key measured time quantities comprising the "time to patient bedside". In practice the “Waiting time” is zero if a team is already in the office and mobilisation times are typically short (about 15 minutes). The largest variability is in waiting times when a team is not immediately available and the journey time to the remote hospital (which depends on traffic and the hospital’s location).

Figure 2 - average hourly demand for emergency retrieval over the 24 hour day

Figure 3 - The average proportion of refusals for an extra shift each day by start time and duration of shift. The red line shows the average refusal when only 2 teams are available (8.0%), corresponding to a “worst case”. The green line shows the average refusal rate if 3 teams were available 24 hours a day corresponding to a “best case” (2.1%). The blue, purple and black lines respectively show proportion of refusals for 8, 10 and 12 hour shifts starting at each hour of the day.

FIGURE 1

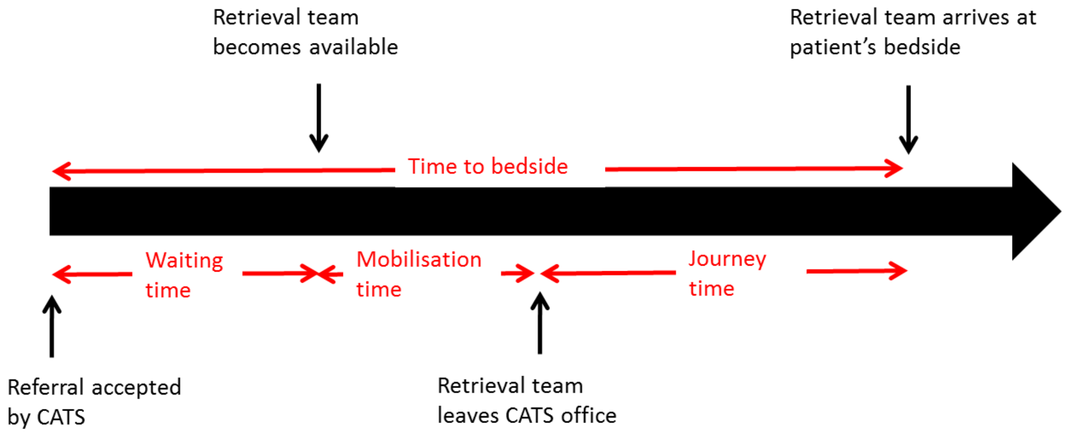


FIGURE 2

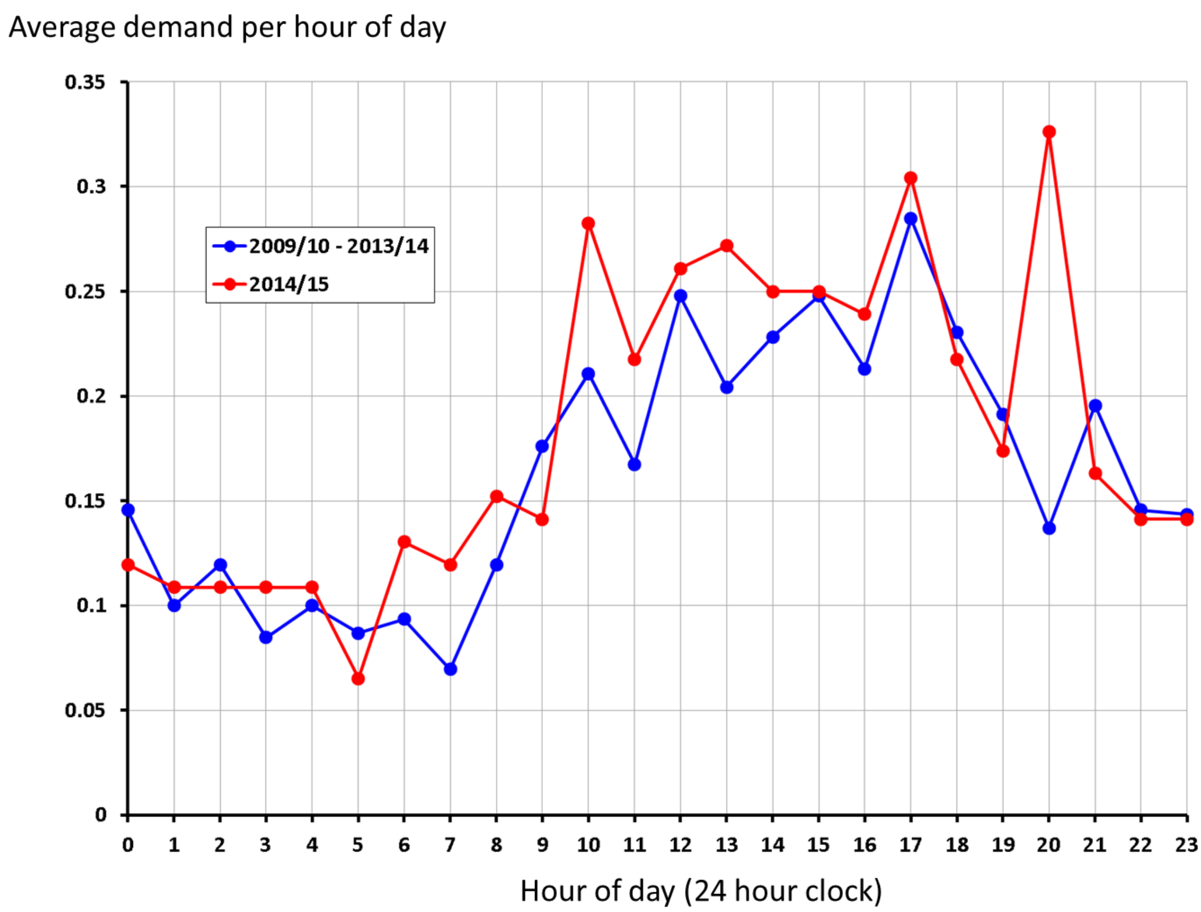
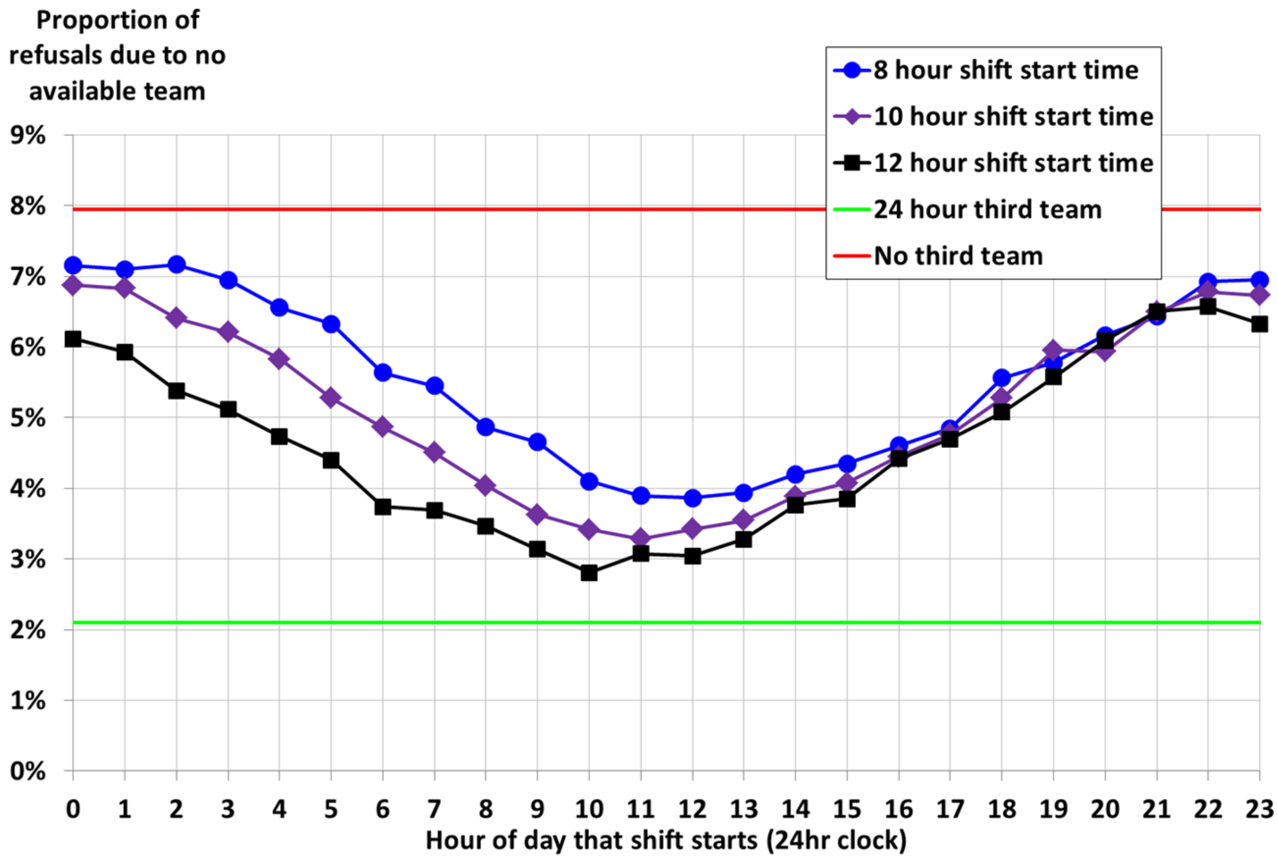


FIGURE 3


Proportion of refusals due to no available team
8 hour shift start time
10 hour shift start time
12 hour shift start time
24 hour third team
No third team
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of day that shift starts (24hr clock)