Manufacturing Engineering Tripos Part 2A, Paper 3, June 2014 – CRIB

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MET2a, Paper 3, Section A, 2014

Sample Solutions

1

(a) Briefly outline the costs that should be considered when determining the appropriate levels of inventory to hold and at what location to hold it.

[15%]

(b) The outbound warehouse of a lubricant production company receives an average of 1,000 barrels per week to send to the wholesaler. There is, on average, 500 barrels waiting already in the outbound warehouse. What is the average time spent in the warehouse by each barrel being sent to the wholesaler?

[15%]

(c) Of the lubricant barrels arriving at the outbound warehouse described above 80% are classed *small* with an average value of £500 and 20% are classed *large* with an average value of £5,000. The processing times of the large and small barrels are identical and hence, on average, 20% of the barrels waiting are large and 80% small. It is proposed to reallocate resources in the warehouse (at no additional cost to the company) so that large barrels are dealt with more quickly with an average waiting time of 0.3 weeks, while small barrels will wait an average of 0.8 weeks before being processed. Assume that the demand for the barrels is unlimited, once barrels are sent the wholesaler pays, barrels are sent individually, and the waiting times for barrels do not affect the product.

(i) Is it worthwhile to reallocate resources as described above? Justify your answer.

[10%]

(ii) By what percentage would the new policy for handling barrels decrease or increase holding cost?

[35%]

(d) The company's main barrel supplier has been having delivery issues. As a result the lubricant company has been subject to some significant disruptions. Discuss the role that inventory might play in managing such disruptions and how it might influence the way it manages its operations.

[25%]

Solution

(a) The following costs should be considered:

- *Cost of capital (opportunity cost)*
- *Depreciation and obsolescence*
- *Handling and storage*
- *Insurance*
- *Cost of ordering*
- *Damage costs*

Cost issues influencing location of inventory: raw materials vs finished goods, on site/off site storage capacities, pull vs push model in place.

(b) Using Little's Law:

R = 1,000 per week. I = 500.

Thus average flow time T = I/R = 500/1000 = ***0.5 weeks.***

(c) (i) Yes, reallocate resources, because T = 0.3 is less than the current average, hence average inventory (=amount of unsold barrels) will decrease on average, and we are told that reallocation can be done at no additional cost.

(c) (ii) Currently the department carries an inventory of 500 barrels worth:

(500)(0.2)(5000) + (500)(0.8)(500) = 700,000 pounds waiting to be sold.

If resources were reallocated flow time of large barrels become:

T_L *= 0.3 weeks.* R_L *= 200/week.*

I_L *= (0.3)(200) = 60 barrels or (60)(5,000) = 300,000 pounds.*

Flow time of small barrels:

T_S *= 0.8 weeks.* R_S *= 800/week.*

I_S *= (0.8)(800) = 640 barrels or (640)(500) = 320,000 pounds*

Total inventory = 300,000 + 320,000 = 620,000 pounds.

Since 620,000 is less than 700,000, the change will reduce the pound value of barrels waiting to be sold.

Thus the change is beneficial.

This is an 11.4% reduction in holding cost. This reduction in holding cost is achieved in spite of the average inventory of barrels increasing from 500 to 700.

(d) Inventory as buffer stock can provide cover against unreliable supply of the raw material (grapes) and component (bottles). Furthermore inventory can be used to buffer against demand uncertainties and internal operational breakdowns. The amount of buffer inventory needed us largely a function of uncertainty the system faces.

Students can also mention that in addition to buffer inventory, inventory as cycle stock is needed. This is the minimum inventory that is necessary to maintain throughput (as per Little's law). Here, throughput rate and lead-time determine the minimum stock needed.

Infliuences on management of operations would include cycle times, staff levels, resource levels, supplier relationships etc.

Examiners Notes:

Most students showed an understanding of the form and use of Little's law and good number were able to evaluate the impact of the company differentiating between small, lower value barrels and large, high value barrels. The final section on the impact of disruptions on inventory and operations was only moderately well answered with some students preferring to write about inventory in general rather than its role in address disruptions.

2.

a) A new consumer goods retailer is setting up its operations in the UK and is examining several logistics issues for its range of product offerings.

(i) Providing an appropriate rationale, explain which types of product it should consider for direct shipping from the supplier to the retail outlets and which types would be more suitably shipped via an intermediate warehouse. [20%]

(ii) Explain what is meant by the term *transhipment* in the context of warehouse management. Indicate under which circumstances the new retailer might consider using transhipment. [15%]

b) For one supplier of a key product, volumes are sufficient that several factories will be used to supply the retailer via intermediate warehouses. Fig 1 provides a table outlining:

- the daily demand at each of three warehouses A, B, C,

- the daily production at each of four supplier factories I, II, III, IV, and

- the transport cost per item between each factory-warehouse pair.

(i) State the basic principles of the North West corner approach for allocating supply to demand. What are the limitations of the approach? [10%]

(ii) Find an initial North West corner allocation for the configuration in Fig 1 and calculate the total distribution cost associated with that allocation. [20%]

(iii) Demonstrate that it is possible to reduce the total distribution cost in part (ii) by at least £100 per day by using a suitable heuristic. [10%]

(iv) A planning change means that the daily demands for Warehouses A, B, C are now 180, 150, 120 items respectively. Discuss the implication of this change for your allocation, and indicate how you would revise your calculations in (ii) and (iii) to accommodate this change. [25%]

	Warehouse A	Warehouse B	Warehouse C	Production
Factory I	(£1.80)	(£1.50)	(£2.80)	180
Factory II	(£2.40)	(£3.60)	(£3.00)	90
Factory III	(£2.20)	(£1.20)	(£1.60)	130
Factory IV	(£4.00)	(£4.20)	(£1.40)	100
Demand	120	210	170	500

Figure 1

Solution

a)

(i)

- *Direct shipping (mostly used for perishable items, high volume goods, high bulk items, and speciality products)*
- *Warehousing (remote production, variable finished-goods demand)*

(ii)

- *Transhipment (retailer) issues*
  - *Shipment of items between facilities at the same level of supply chain*
  - *Balance stocks*
  - *Match demand trends*
  - *Risk reduction*
  - *Cost v response trade off*

b)

(i)

- *Create a matrix of sources and destinations*
- *Set initial allocation from NW corner*
- *Calculate the change in cost of supplying one unit from each currently empty cell while preserving demand/supply rim conditions (opportunity cost)*
- *Reallocate the maximum possible quantity (subject to rim conditions) to the lowest cost cell, following the path evaluated.*
- *Solution is optimal if all the opportunity costs are zero or positive*

Limitations of algorithm

- *heuristic: feasible but not optimal*
- *Sensitive to starting point selected*
- *Complex for multiple item types*
- *No transport variations*
- *Fixed supply / demand*

(ii)	*Warehouse A*	*Warehouse B*	*Warehouse C*	*Production*
Factory I	*(£1.80)* ***120***	*(£1.50)* ***60***	*(£2.80)*	*180*
Factory II	*(£2.40)*	*(£3.60)* ***90***	*(£3.00)*	*90*
Factory III	*(£2.20)*	*(£1.20)* ***60***	*(£1.60)* ***70***	*130*
Factory IV	*(£4.00)*	*(£4.20)*	*(£1.40)* ***100***	*100*
Demand	*120*	*210*	*170*	*500*

Total Cost = 120 x 1.8 + 60 x 1.5 + 90 x 3.6 + 60 x 1.2 + 70 x 1.6 + 100 x 1.4

= 216 + 90 + 324 + 72 + 112 + 140

= £954 per day

(iii) To improve the allocation in terms of cost, we follow the approach above and test each empty cell in turn to determine the effect of adding one item to that cell would be while taking away the necessary amount from the non zero cells.

The incremental cost associated with each cell is in [ ]

e.g. cell (2,1) = 2.4 – 3.6 + 1.5 – 1.8 = -1.5

	Warehouse A	*Warehouse B*	*Warehouse C*	*Production*
Factory I	*(£1.80)* ***120***	*(£1.50)* ***60***	*(£2.80)* *[0.9]*	*180*
Factory II	*(£2.40)* *[-1.5]*	*(£3.60)* ***90***	*(£3.00)* *[-1.0]*	*90*
Factory III	*(£2.20)* *[0.7]*	*(£1.20)* ***60***	*(£1.60)* ***70***	*130*
Factory IV	*(£4.00)* *[2.7]*	*(£4.20)* *[3.2]*	*(£1.40)* ***100***	*100*
Demand	*120*	*210*	*170*	*500*

Cell (2,1) has the greatest reduction in cost. A new allocation based on reallocating the maximum of 90 items to Cell (2,1) is given by

	Warehouse A	*Warehouse B*	*Warehouse C*	*Production*
Factory I	*(£1.80)* ***30***	*(£1.50)* ***150***	*(£2.80)*	*180*
Factory II	*(£2.40)* ***90***	*(£3.60)* ***0***	*(£3.00)*	*90*
Factory III	*(£2.20)*	*(£1.20)* ***60***	*(£1.60)* ***70***	*130*
Factory IV	*(£4.00)*	*(£4.20)*	*(£1.40)* ***100***	*100*
Demand	*120*	*210*	*170*	*500*

We don't need to recalculate the total cost as it is just given by:

-1.5 x 90 = -£135.

(iv)

Add an extra "demand" point – Warehouse Z - with zero cost to absorb surplus supply. i.e.

	Warehouse A	*Warehouse B*	*Warehouse C*	*Warehouse Z*	*Production*
Factory I	*(£1.80)*	*(£1.50)*	*(£2.80)*	*(£0.00)*	*180*
Factory II	*(£2.40)*	*(£3.60)*	*(£3.00)*	*(£0.00)*	*90*
Factory III	*(£2.20)*	*(£1.20)*	*(£1.60)*	*(£0.00)*	*130*
Factory IV	*(£4.00)*	*(£4.20)*	*(£1.40)*	*(£0.00)*	*100*
Demand	*180*	*150*	*120*	*50*	*500*

Also the solution will be degenerate because demand for Warehouse A exactly matches output of Factory 1, so an additional ε would need to be added to the initial allocations e.g. for factory II and Warehouse A as per the allocation below.

	Warehouse A	*Warehouse B*	*Warehouse C*	*Warehouse Z*	*Production*
Factory I	*(£1.80)* ***180***	*(£1.50)*	*(£2.80)*	*(£0.00)*	*180*
Factory II	*(£2.40)* ε	*(£3.60)* ***90***	*(£3.00)*	*(£0.00)*	*90*
Factory III	*(£2.20)*	*(£1.20)* ***60***	*(£1.60)* ***70***	*(£0.00)*	*130*
Factory IV	*(£4.00)*	*(£4.20)*	*(£1.40)* ***50***	*(£0.00)* ***50***	*100*
Demand	*180*	*150*	*120*	*50*	*500*

The subsequent improvement operations would then work as before.

Examiners Notes:

Most students answered well on the role of warehousing, but quite a number did not understand the role of transhipment. The main section of the question, relating to the allocation of factory outputs to warehouses (using the so called North West Corner method) was generally done very well. Most students managed the initial calculation and a good number were then able to apply the adjustment heuristic although some made rather elementary calculation errors. The last section, in which demand distribution & volumes were changed – leading to unbalanced supply v demand – was moderately well attempted. A number of students failed to notice that the system was now ill conditioned which requested a minor adjustment to the calculation.

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SECTION B

Question 3

Question 3 (a) Define 'manufacturing strategy'. Explain why it is essential to understand the manufacturing strategy of a company before applying industrial engineering techniques to the redesign of a production system.

Manufacturing strategy is a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate in order to meet a set of manufacturing objectives which have been derived from business objectives.

It is essential to understand the strategy so that we have a clear identification of the objectives of the production system that we are designing.

(b) Briefly outline the basic procedure for Method Study

The basic procedure for method study is as follows:

SELECT the work to be studied.

RECORD all the relevant facts about the present method by direct observation

EXAMINE those facts critically and in ordered sequence

DEVELOP the most practical, economic and effective method

DEFINE the new method so that it can always be identified.

INSTALL that method as standard practice.

MAINTAIN that standard practice by regular checks

(c) *Discuss the factors you would include in an audit of the physical working environment of a factory comprising a forge, a general machine shop, and an assembly department. Explain why each factor would be included, relating it to the effect it might have on human performance, and identifying the areas where it is likely to be particularly important.*

Factors are best structured into 3 areas: Visual environment inc. lighting: Auditory Environment and Noise; Climate.

Factors:

Visual: light intensity, both background and focused; contrast between workpieces and background, colour contrasts, and colour rendering of lighting, extraneous glare – uncontrolled light. Look for availability of aids to improve visual angle for precision work

Potential problems, eye strain, headaches, process errors. Least likely in forge most likely in inspection of fine machining or in close precision assembly work.

Auditory: sound intensity (loudness); duration of exposure; frequency (pitch);continuity (continuous, intermittent, impact, impulse). Look for control measures, provision of hearing protection,sound enclosures.

Potential Problems: Distraction; Startle response - due to sudden loud noise, causes spontaneous muscle contractions, blinking eyes, head-jerk movement; Negative emotions such as annoyance, frustration, anger, and fear; Interference with conversation, thinking, and other cognitive processes; Interference with sleeping; Temporary hearing loss; Permanent hearing loss. Noise in forge, impact noise, noise in m/c shop continuous noise, noise in assembly. likely to be low

Climate Air temperature; Humidity - usually relative humidity; Air movement; Radiation from surrounding objects, including the sun. Look for control measures, heating or air conidioning, fans

Potential Problems: Heat:Heat rash - areas of skin erupt into red or white bumps due to inflammation of sweat glands; Heat cramps - spasms of muscles in physical labour; Heat exhaustion - muscle weakness, nausea, dizziness; Heatstroke - fever, dry skin, convulsions, coma (in extreme cases: death). Cold:Hypothermia. Potential heat related problems in forge, unlikely elsewhere. Maybe draughts in m'c shop and assembly

(d) A male worker works an eight-hour shift consisting of performing a repetitive task with a 8-min work cycle. During each cycle, his energy expenditure rate is 9 kcal/min for 25% of the time, and 5 kcal/min for the remaining 75%. Suggest a suitable schedule for rest breaks.

During task Average *ERwrk* = 9(0.25) + 5(0.75) = 6.0 kcal/min (ER is energy rate

Recommended max mean energy expenditure over 8 hour shift = 5.0kcal/min

MER = (*TwrkERwrk* + *TrstERrst*)/(*Twrk* + *Trst*)

Rearranging: MER(*Twrk* + *Trst*) = *TwrkERwrk* + *TrstERrst*

Collecting terms: Trst(MER - *ERrst*) = *Twrk*(*ERwrk* - MER)

Hence: Trst = *Twrk*(*ERwrk* -MER)/(MER- *ERrst*)

Trst = 8(6.0 – 5.0)/(5.0 – 1.5) = 2.29min

On average the worker should rest for 17.2 minutes for each hour of work. Any sensible schedule to achieve this is acceptable. E.g. alternating 15 and 20 minute breaks after each hour of work.

(e) Define the following terms, and briefly describe their use in the design and operation of a manufacturing system:

(i) Takt time;

(ii) Poka-yoke;

(iii) Overall Equipment Effectiveness (OEE);

(iv) Kaizen.

(i) Takt time

Takt time is defined for an operating unit as *EOT* / *Qdd*

where, *EOT* = effective daily operating time, *Qdd* = daily quantity demanded

Takt time represents the 'drumbeat' at which the operating unit must work, hence the work must be designed, and the necessary resources provided so that the operation cycle time is consistent with the takt time.

(ii) Poka-yoke

"Poka-yoke" – Japanese word meaning prevention of errors using low cost devices to prevent or detect them. Poka-yoke devices can prevent errors such as:

Omitting processing steps, Incorrectly locating a part in a fixture, Using the wrong tool,Neglecting to add a part in assembly

(iii) Overall Equipment Effectiveness (OEE)

OEE = (Equipment Availability)(EA) x (Equipment Efficiency Performance)(EEP) x (Equipment Quality Performance)(EQP)

Equipment Availability (EA) Measures how long equipment is not producing parts due to unplanned downtime = Actual Equipment running time / Scheduled running time

Equipment Efficiency Performance (EEP) measures actual machine output versus theoretical or standard machine output

EEP= (Standard Cycle Time) x (No. of Parts Produced)/ Actual Equipment running time

Equipment Quality Performance (EQP) measures quality in terms of % of good product

EQP = 100 (No. of good parts)/(Total No. of parts produced)

Measuring OEE and its component parts identifies weak areas of performance, and provides a basis for identifying where improvement projects might make an impact.

Iv) Kaizen

"Kaizen" is a Japanese word meaning continuous improvement of production operations, and is a fundamental part of so called 'lean manufacturing'. It is usually implemented by worker teams, sometimes called "quality circles". It can be seen both as a philosophy and as a set of tools. The basic idea is to instil in workers a sense of responsibility for every task they carry out, and to continually improve the performance of the task.

(f) i) Using Garvin's Dimensions of Quality, or otherwise, discuss what is meant by product quality.

ii) In the context of capability measurement, discuss what is meant by C_p and C_{pk}.

iii) A manufacturing process has a defect rate of 8 percent, based upon 30 samples of 40 data points each. Calculate the control limits for a p-chart, and explain how it would be used to detect changes in the process performance.

i) Garvin's dimensions of quality are summarised below. A discussion of these would provide a good answer to the question.

Performance – primary operating characteristics

Features – other secondary characteristics

Conformance – meeting specifications

Reliability – consistency of performance

Durability – product life

Serviceability – ease of service

Aesthetics – effect on senses

Perceived Quality – brand image / reputation

(ii) C_p and C_{pk}

C_p and C_{pk} are measures of process capability. They are used to compare the "natural variation" of a manufacturing process to the specified tolerance of the product being produced.

$$\hat{C}_p = \frac{USL - LSL}{6\hat{\sigma}}$$

$$\hat{C}_{pk} = \min\left[\frac{USL - \hat{\mu}}{3\hat{\sigma}}, \frac{\hat{\mu} - LSL}{3\hat{\sigma}}\right]$$

where σ is the standard deviation of the process, μ is the mean of the process

USL and LSL are the upper and lower specification limits of the product.

Manufacturing systems should be designed with capable processes. A C_P of 1 denotes a capable process – but to allow for drift, 1.33 is often used as the acceptable minimum. C_p does not allow for product centring, while C_{pk} does. A process operating with C_{pk} =1.33 will produce 63 defects per million operations

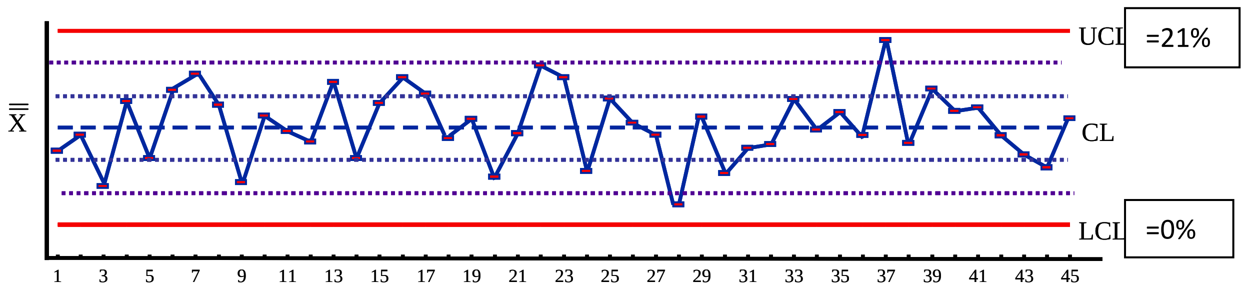
iii)

P chart

p	0.08	CL-p	0.08	
n	40	UCL-p	0.209	
1-p	0.92	LCL-p	-0.049	= 0
p*(1-p)/n	0.0018			
sigma	0.043			

Note: for a p chart n is calculated from the number of data points per sample, not the number of samples which can vary dependent on how long the process had been assessed. The lower control limit cannot be negative so is set at zero.

Samples of 40 are taken at intervals and the % defective calculated. This % is plotted on a control chart. (see fig.) While the process remains 'in control' subsequent plots should be randomly distributed around the 8% line. Changes to the process will be shown by variation from this, for example, by trends, or several subsequent samples being between warning and control limits. There are various rules used to interpret the significance of such variation, better students might give examples.



Examiners Comment

This question addressed 6 separate topics in the 3P5 course. Because of the breadth, this question provided an excellent test of the comprehension of the course as a whole. The quality of answers to each topic covered a wide range. The qualitative parts were generally more discriminatory than the quantitative parts but overall there was excellent discrimination among the students.

4 *(a) Explain why companies have standard times for manufacturing operations.*

(b) Outline the main methods used for setting time standards, and compare the relative advantages and disadvantages of using time study or predetermined motion time systems (PMTS) for this task.

(c) An industrial engineer measured the time taken for 3 successive repetitions of a simple light assembly operation. The results were: 28.6s; 31.4s; and 30.0s. Analysing the operation using MTM-1 resulted in a time of 1104 TMU. The standard time for the operation was recorded as 37.6s. in the company's production engineering database.

i) Calculate 95% confidence limits for the observed time.

ii) Calculate the basic time from the MTM analysis.

iii) Compare these times with the time in the company's database, comment on any differences and explain why such differences might occur.

a) Standard times are required for:

- Production Planning
  - Capacity
  - Loading
  - Scheduling
  - Machine and operation balancing
- Costing and estimating
- Comparison of alternative methods
- Incentive and payment schemes

(b) Time standards are generally set by either time study or predetermined motion time systems (PMTS). They can also be set via activity sampling or analytical estimating.

Time Study

Time study is a technique for measuring the times and rates of working for the elements of a specified job, and for analysing the data to establish the time necessary for carrying out the job at a defined level of performance.

1. If the purpose of the time study is to establish a standard then it is **essential** that the operation has been subjected to method study first.

2. The worker to be studied must have the necessary physical and mental attributes, the necessary levels of knowledge and skill and be familiar with the operation (ie have done sufficient repetitions to have got beyond learning curve effects.)

3. Obtain and record basic information about the part/operation, the details of the process eg equipment used, jigs, tools, speeds & feeds etc., the operator, the working environment.

4. Observe the operation and break it down into a number of elements.

5. Over a number of cycles measure the time taken for each element and for each assess the effective speed of working of the operative (rating).

6. Convert the observed times to "basic times“

7. Determine the allowances to be made on top of the basic time. 8. Determine the work content and standard time for the operation.

Summary of Standard Time

Basic Time = Observed time x Rating/Standard Rating

Work Content = Basic time + Relaxation Allowances + Allowance for Extra work

Standard Time = Work Content + Allowances for delay, unoccupied time, interference

<u>PMTS systems</u>

A PMTS comprises a database of basic motion elements and their associated normal time values, together with procedures for applying the data to analyze manual tasks and establish standard times for the tasks

Basic motions include, for example: Reach, Grasp, Move,Release. To set a time using PMTS, the analyst has to decompose the activities into basic motions and determine the parameters for each motion, for example type and length of REACH, The time for that elemental motion is obtained from the database. The times for all the elemental motions are summed to give the overall time.

<u>Comparison of PMTS systems and time study</u>

- PMTS systems generally produce a more detailed description of the work than time study.

- In PMTS each basic motion is described along with its variables, so alternative methods can be readily compared using time as a criterion. In time study, alternative methods need to be timed to enable comparison.
- With PMTS methods can be developed and standards established before production operations start.
- PMTS are objective and consistent, they do not require the assessment of rate of working and the use of the stop watch as is required in time study. This can remove one of the impediments to good industrial relations.
- PMTS systems are not affected by learning curve effects, but on the downside cannot be used to set temporary standards in learning situations.
- However, PMTS systems are complex and very time consuming to apply. For example, MTM1 takes typically 240 minutes of analysis for 1 minute of work. Time study is generally much quicker to apply. The training of PMTS specialists is lengthy.
- PMTS systems are most suited to high volume, repetitive, short cycle time operations. For all other situations time study is likely to be more appropriate.

(*c)*

i) From the data mean is 30s and sample standard deviation is 1.4

Confidence limits are:

$$\bar{x} \pm \frac{t_{n-1}^{1-\alpha/2} s}{\sqrt{n}}$$

t from tables is 4.303, n is 3. Hence limits: 30 +/- 3.5 (33.5 – 26.5)

ii) Basic time = 1104x 0.036x0.83= 33.0s

iii) From time study	26.5-33.5s
From PTMS	33.0s
From database	37.6

First thing to note is that database gives standard time, PTMS is basic time, and time study is observed time.For comparison we should convert to common base. Typical relaxation allowance for light assembly is 14%. Applying this would give a database basic time equivalent of 33.0s. Hence there is complete agreement between PTMS and database.

Time study average time is lower, but we need to apply rating to get to basic time. We have no information on rating but one explanation is that the worker is working at a rating higher than 100. (110 in this case would bring basic time to 33.0s). An alternative explanation is that as the 90% confidence interval includes the dbase time the worker could be working at a 100 and the difference could just be random error.

An explanation that the worker has made learning curve improvements is unlikely as the PMTS time agrees with the d/base.

Examiners Comment

This question tested knowledge of the reasons for work measurement, the main methods used, and the advantages and disadvantages of each, and then tested application and critical analysis. Most students knew several reasons for work measurement, but few had a comprehensive grasp of all reasons. Many students were able to describe the main methods used, but in varying levels of detail and this provided good discrimination. The critical aspects, comparing advantages and disadvantages (in 4b) and particularly explaining differences in times (in 4ciii) were the least well answered. The quantitative parts were generally well answered.