MANUFACTURING ENGINEERING TRIPOS PART II, 2008
Examiner: Dr W. O'Neill
CRIB

Question One: Mr D Probert

(a) The principal approaches to be used are:

- Design for Assembly (DfA)
- Variations of DfA, generically called DfX, which consider other aspects of the consequences of design, such as whole life cost, ease of disassembly and disposal, etc depending on what is important in the business context.
- Value Analysis (VA)
- Value Engineering (VE – usually considered the consequence of VA)

These techniques have been covered in module teaching and students should be able to give an account of what they set out to achieve and how they are applied.

In terms of the current/future product and advantages/limitations issues, the following table gives a summary:

Approach/ technique	Application to Products		Advantages of technique	Limitations of technique
	Current	Future		
DfA	Limited application to existing products, unless cost of redesign can be justified	Best applied to future products, main scope for improvement is at this stage, without incurring significant additional cost	Systematic and thorough	Can become very detailed and consume a lot of effort.
DfX	As above	As above	Can be tailored to suit the business context	Methods are not as well defined as in DfA
VA	Can be usefully applied to current products, to provide a range of scope for continuous improvement, not just assembly methods	Not generally applied to future products, although can be useful in appraising design options	Comparatively straightforward, can be applied at varying levels of detail	May now be clear how to ascribe cost to functions, although the resulting discussion is useful
VE	Not all	The consequences	As above	As above

	improvements suggested will be viable, but application to current products is generally useful.	of VA/VE as applied to past and current products can often be carried for to future products		

Theses techniques are best used together, and certainly VA/VE are often regarded as synonymous. VA/VE can suggest areas where the more detailed analysis of DfA would be beneficial.

There are also other analytical techniques that could be applied for a similar purpose: QFD (quality function deployment), the Kano model (a review of design feature benefits to the customer) and life cycle analysis.

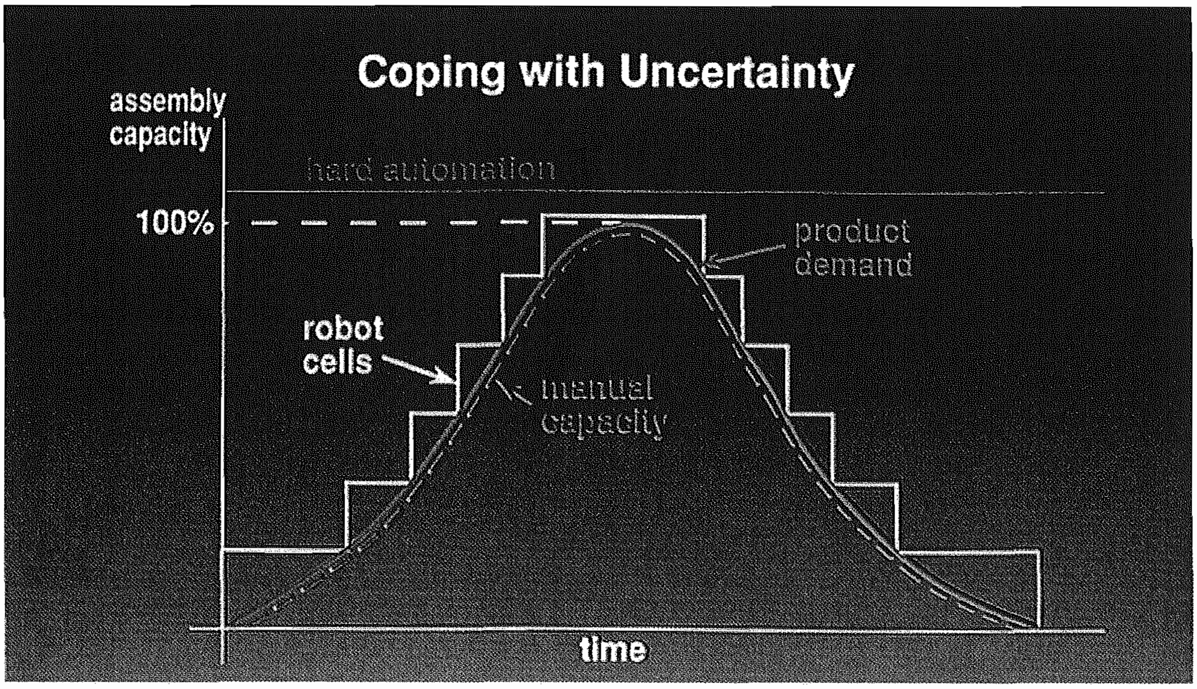
(b) Factors to take into account include: flexibility, reliability, quality, speed, capital investment, running costs, volume growth and lifecycle of the product, hazards (to assembly operators). Component and task variability are also important considerations.

Students may quote the Puttick grid (covered in lectures) which categorises products according against two axes:

- production volume and market certainly
- intrinsic product complexity (including variety)

The manufacturing system, and its degree of automation, will be quite different for the four quadrants of this grid.

From these factors, students should also consider whether manual assembly, hard or soft automation is appropriate. In this context the graph below, presented during the teaching module, will be useful. It compares the fixed capacity of hard automation with a robot cell solution (soft automation) and manual assembly, through the product lifecycle.



A rule of thumb for the cost of hard automation may be given: £25k to £30k per part for a typical system operating at a cycle time of a few seconds.

Some students may suggest outsourcing manufacturing to low cost locations. In this case the logistic and quality risks should be considered.

(c) Consideration of whether to develop the software in-house or to go outside to a supplier should cover such issues as know how, capacity, cost, business focus and flexibility.

The characteristics of software that make it comparatively difficult to outsource (compared to other hard components) include its complexity, changeability and invisibility.

Good students will be able to review the issues included in the software sourcing checklist (covered in lectures) which are categorised into business interest, task suitability, supplier suitability and collaborative arrangements.

In addition, the development process for software could be described, linked to a discussion about whether the company was capable of managing this.

Examiners Comments:

This question was answered by every candidate. Most candidates were able to deliver reasonably comprehensive answers when discussing design improvement principals, although marks were often lost due to limited or no discussion of the comparisons, advantages or limitations. Candidates often failed to include discussion of the variations or DfA or VA. Section b was answered well in most cases, with many candidates offering a detailed discussion of the Puttick grid including an assessment of the decision making process. Section c provided a wide range of answers, from cursory discussion of the decision making process to detailed deliberations. Good answers presented a clear *approach to the problem often using the software sourcing checklist to support their answer. High scores were obtained for highlighting the information required and conditions that must be met to test collaborator suitability and outsourcing opportunity. Many candidates did well in answering this question with many high scores. Low scoring answers lacked detail and were badly structured.*

Wo207@eng.cam.ac.uk

Question Two: Dr C Barlow

(a) E.g. (i) Rolls Royce Joint Strike Fighter (JSF) Blisk. Involved new production methods and factory redesign. (ii) Composite wing for commercial aircraft (Airbus 380) from GKN. (iii) Iron ore processing plant in Australia which was taken directly from lab scale to commercial plant; the process did not scale-up and the 3 billion $ plant never worked.
Pre-production is a 'test run' when production problems can be identified and solved without financial penalties. Once full production starts, any delays are problematic. So pre-production introduces new technologies; demonstrates manufacturing capability ahead of full production load; demonstrates that processes can be scaled-up from small-scale to large-scale; ensures factory layout is appropriate; commencement of recruitment and training; helps to ensure that the supply chain is operating correctly so that satisfactory material and parts are available for full production.

(b) (i) Long-fibre CFRP is likely to have an epoxy (thermoset) matrix. Chopped-fibre CFRP may have a thermoplastic matrix so that it can take advantage of polymer manufacturing technologies; the absence of continuous fibres means that the mechanical properties are less good (lower elastic modulus). Advantages over conventional materials (mild steel or Al alloys): High specific strength (σ/ρ); Enhanced specific modulus (E/ρ); good fatigue resistance (cf aluminium); good environmental resistance (no rusting). Applications: Structural members; body panels; vibration absorbers; leaf springs.

(ii) Material and assembly/fabrication costs are both high, and the low volumes create a vicious circle which inhibits cost reduction; also, neither design nor process technology can be transferred to CFRP from metals. Material: carbon fibre is intrinsically expensive because of the slow manufacture process. This cost will fall as new rapid processes are introduced (imminent). Epoxy is relatively expensive compared with commodity polymers, but again this is related to the comparatively low volumes manufactured. Fabrication: a skilled and labour-intensive process, still a craft. Use of pre-preg is seen as the way forward, but existing processes can be automated only to a limited extent. With significantly increased volumes, new processes would be forced to develop, but the current volumes do not justify the development costs.
Design: designs which are appropriate for metals are not so for CFRPs, so composite-specific designs are needed. This is particularly difficult for joints, where secondary stresses must be minimised.

Moving from conventional materials to CFRP requires a complete change in assembly route. New machinery, new shop floor processes, extensive staff training in very different techniques and skills. So an existing factory is most unlikely to make the transition. New plants might be set up using CFRP, but these will represent either a new business, or expansion of an existing business into a new area.

A CFRP car using an exoskeleton (roughly equivalent to a space frame) could simplify production methods dramatically.
Nevertheless, the materials advantages which can be gained from CFRP are great enough that the material is seen as having a future. It has already penetrated the aerospace sector, and automotive is likely to follow.

(iii) Looking at LCA, we need to consider resource implications of material manufacture; fuel savings resulting from using CFRP rather than any other material during the lifetime of the vehicle, and disposal/recycling implications.
CFRP is resource-intensive to manufacture, but so are steel and aluminium.
CFRP is likely to be lighter than competitor materials, so fuel advantages would be expected.

Automotive sector implies a requirement for recyclability. which is not currently viable with a thermoset matrix, but is commonly practiced with Al and steel. Thermoplastic matrix composites are generally more expensive but could be recycled; however, volumes are currently too low for this to be economic. Long fibres would be broken down by the recycling process so the material would be degraded. The recycled material would however be suitable for conventional polymer manufacturing technologies such as extrusion and injection moulding.

Examiners Comments

This question was also popular with 33 candidates choosing to answer. The marks were duly spread with most candidates being able to provide reasonably good answers to the section on pre-production stage. High scoring answers provided in depth deliberations and a wide range of examples in support. Low scores were once again a result of limited depth of discussion. The section on CFRP materials was covered well in most cases with low scores offering few examples, and limited discussion of the comparisons with conventional materials. The Barriers to introduction section was generally answered well, although candidates often focused too much on fuel savings alone rather than extending their discussions to include the cost, volume and lifecycle consideration of the material itself. Those students that had a good appreciation of sustainability and materials scored highly here.

Wo207@eng.cam.ac.uk

Question Three: Dr K Platts

i) Accuracy is affected by three components: the accuracy of the robot; the accuracy of the end effector, the accuracy of the fixture.

Students should briefly discuss each. Robot accuracy depends on the construction of the robot, the speed at which it is operating and the position in its workspace. Fixture and End effector accuracy depend on the design. Both robot and end effector need to take into account deflections if high forces are required. To improve accuracy, where possible design fixturing and end effectors to position components against solid locations (use principles of kinematic location). If this is not possible, use a kitting device to hold parts, or to position parts, in a known location and then maintain that location through subsequent operations. Use the robot technical manual to obtain the specifications for accuracy of positioning (and tracking if req'd) and ensure that these are acceptable for the operation.

ii) Students were introduced to the following:
Collision detection
Collision avoidance
2D vision
3D vision
Linetracking with vision
Force sensing
Robot link

Discussion and examples of each were given in lectures.

iii) Advantages of SCARA: Stiffer and hence able to perform more accurate operations, or to perform faster at a given level of accuracy. Cheaper than anthropomorphic of equivalent size. Suitable for pick and place, and assembly involving vertical stacking.
Disadvantages: 3 dof hence restricted access to workspace

Anthropomorphic: 6 dof , hence very versatile, can mimic human motion hence suitable for tasks requiring complex motion, spray painting, seam welding.
Disadvantages: Expensive, less rigid, hence slower or less accurate.

Examiners comments

Not a popular question with 8 attempts. A low class average suggests more enthusiasm than ability when it comes to answering a straightforward question on modern industrial robotics. Some answers were indeed absent of any useful detail. Many candidates gave cursory descriptions of methodologies of intelligent sensing for example. The better answers were able to offer detailed technical discussions that clearly demonstrated knowledge in this area.

Wo207@eng.cam.ac.uk

Question Four: Dr A Parlikad

a)

Characteristics of MRP	Characteristics of JIT
▪ anticipates future demand ▪ copes with product and process complexity ▪ OK even for infrequent, low-volume parts ▪ PUSH ▪ Potentially increases WIP	▪ reacts to demand ▪ potentially reduces WIP ▪ best for simple products and simple routings ▪ requires level scheduling ▪ PULL ▪ MRP for overall control, JIT for internal control

b)

i. By building a computer simulation model, bottlenecks can be established by examining the average queue lengths and queuing times in front of each process. In order to build the simulation model we require the following information:
   a. arrival rate of parts into the production floor
   b. operation times for the different processes
   c. capacity restrictions, if any

ii.

Actions	Effect on volume output performance	Effect of delivery performance
Reduce Set Up Time – SMED	Initial major step change improvement as more machine time available to actually machine until volume output rate equals bottleneck rate – then none	Possibly an initial minor improvement as backlog of orders cleared – then none and may regress
Balance the line	Initial major step change improvement as machine idle time reduced until volume output rate equals bottleneck rate – then none	Possibly an initial minor improvement as backlog of orders cleared – then none
Introduce kanbans	No effect but WIP reduced	A minor improvement as orders more visible
Introduce self inspection	Initial minor step change improvement as more machine time available to actually machine good parts until volume output rate equals bottleneck rate – then none	Possibly an initial minor improvement as backlog of orders cleared – then none
Dedicate Heat Treatment Capacity	Initial major step change improvement as throughput increased until volume output rate equals bottleneck rate – then none – may require careful management	Possibly an initial minor improvement as backlog of orders cleared – then none

iii. Invest in small heat treatment units in the digger cell itself sized to take its small batches. Or Buy a second borer and mill and dedicate the new machines to the post heat treatment process.

c) Choosing the "best" inventory management system depends on numerous parameters, among the most important of which are supply chain-related parameters, such as the demand pattern, the demand level, and the inventory costs. MRP is more appropriate for companies where there are many product options, frequent engineering changes and fluctuating product system, whereas JIT is more appropriate in environments where there are relatively few product options, engineering changes, product mix changes, and there is less variability in demand levels. A combined JIT/MRP system is more suitable in this situation: use JIT for the car manufacturers since the demand is fairly stable, an MRP for the digger cell, since there is a large variety.

Examiners Comments

Another unpopular question which 35 candidates. This question explored JIT, MRP, and process flow for the production of transmission components. The comparison between JIT and MRP was understood well by most candidates. Answers to section b were mixed, with a small collection of comprehensive answers and many more limited deliberations especially concerning the answers for section b ii. Section c produced some interesting answers, with candidates opting for one or the other and few offering a combined MRP/JIT approach.

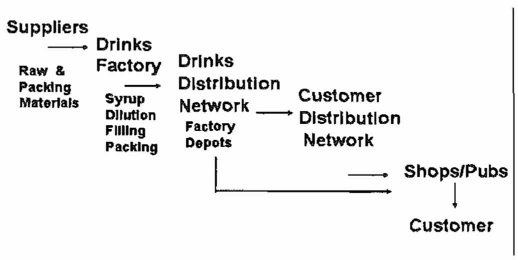
Wo207@neg.cam.ac.uk

Question Five: Dr W O'Neill

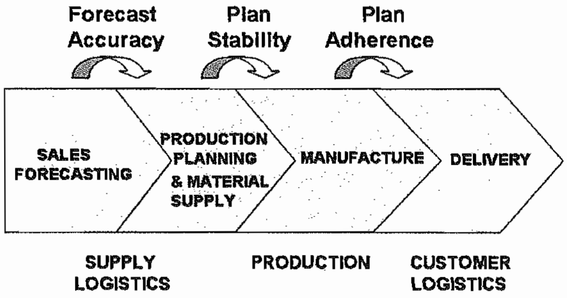
In the context the process industry concerned manufactures food stuffs, i.e., soft drinks. Typically the manufacturer obtains ingredients from a range of suppliers, mixes or formulates ingredients to recipes, packs them and despatches to customers or to distributors' logistics operations. Thus the supply chain consists of:-

- Suppliers of ingredients
- Suppliers of packaging materials
- In-bound logistics including warehousing
- In house processing
    - Ingredient preparation
    - Formulation
    - Packaging
    - Quarantine for QA (if necessary)
- Out-bound logistics
    - Despatch to distributor
    - Delivery to customer

The supply chain can be shown as follows.



The supply chain must also be monitored in order to affect control over the full manufacturing cycle. In the case of a soft drinks manufacturer the supply chain can be described as follows.



Performance measures include:
Sales Forecasting:

A soft drinks manufacturer is a "Make-to-Stock" company – the lead-time from an order to delivery can be 24 hours or less. In this case it is very important need to forecast and to plan the production and stock levels. Products such as soft drinks are often heavily promoted products and so very variable demand levels exist. Sales forecasting also helps to determine the expected demand on the suppliers for raw & packing materials. It also allows one to determine expected demand on the factory production lines & labour both short & long term. Sales forecasts are also used in to provide information for Business forecasting of profit etc.

Production Planning:

Planning is a necessary function within any organisation that produces something. In the manufacturing environment this function is often complex because of the rate of change, number of parts, and occurrences of unplanned events. There are several different methodologies used depending on the product. However, the objectives remain the same for any product; efficiency (minimisation of waste) and effectiveness (supply to demand). Planning is carried out so that activities and resources are co-ordinated over time to achieve the goals with as little resource consumption as possible. Planning must be done so that the progress of the plan can be monitored at regular intervals and control over operations can be maintained. Planning in the manufacturing environment involves four elements: scheduling, labour planning, equipment planning, and cost planning.

- Scheduling involves specifying the start, duration, and end of the various activities
- Labour planning involves allocation of personnel, distribution of responsibilities and resources
- Equipment planning involves identification of types and need of equipment
- Cost planning involves identification of costs and when they will occur

Monitoring:

It is important to provide monitoring of all operations in order to identify any variations from plan. *Sales Forecast Accuracy* Monitoring is one such tool used to assess the accuracy of forecasts one or more weeks out, at the major customer level. *Factory Performance Monitoring* is used to determine the Adherence to Plan and identify any issues that have arisen during the production operations that may impact on the expected outputs. *Plan Stability Monitoring* is the means by which one can determine the number and size of changes that occur within a particular plan over an agreed horizon. The reasons for any change are recorded and fed back into the information database for the next planning activity.

b)

Manufacturers know that sales of Soft Drinks depends on how good a summer it is. But the question remains, what does a "good" summer mean and what should you do about it. The best possible approach is to try and gather historical data on the definition of a "good" summer, i.e. a Summer Factor that incorporates average temperature & hours of sunshine across the summer months, i.e. June to August (or May to September). It would be prudent to compare this with the average of the last 50 years to get a comparative figure. The strategy could be as follows.

- Decide the Maximum Summer Factor you want to be able to cope with.
- Estimate what uplift in sales by product this is likely to produce (over 5 or more weeks).
- Agree the maximum production capability by week.
- Determine minimum stock level to still ensure adequate Customer Service.
- Calculate starting stocks of each product type required.
- One must then determine if this level of Stock acceptable to the Business? Cost of "Insurance Policy".

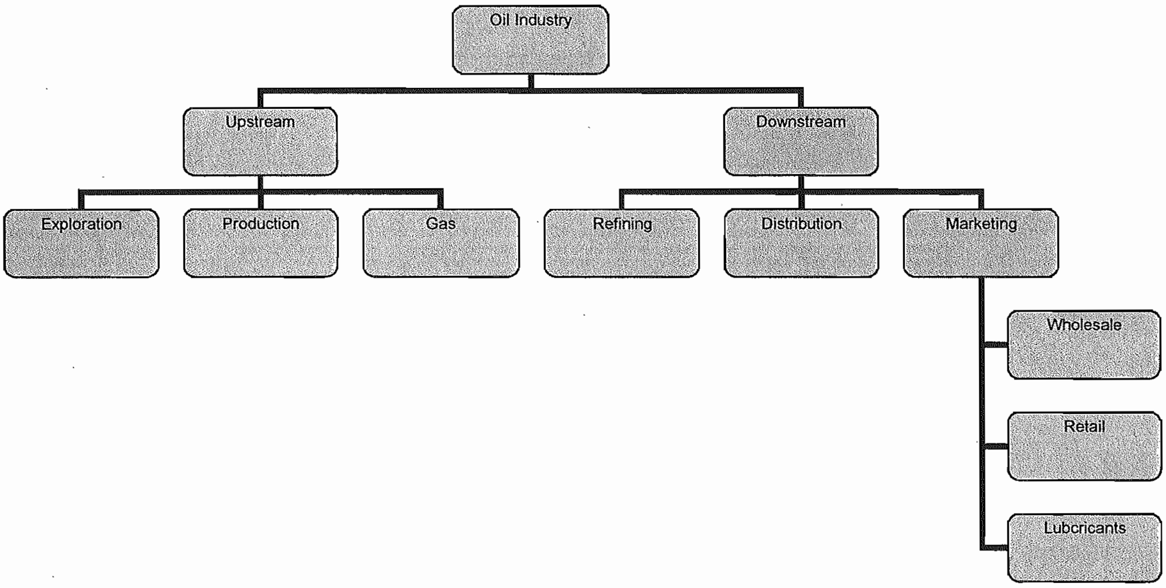
Examiners Comments

This question was also popular with 35 candidates choosing to answer. The majority of candidates have a good grasp of the issues relating to the operations and practices in the process sector and were able to provide comprehensive answers to most parts of the question relating to supply chain structures and performance measures. Although, the exception being the limited answers on monitoring of operations, both factory performance, and plan stability monitoring.

Wo207@eng.cam.ac.uk

Question 6: Dr W. O'Neill

a) The oil industry is characterised by upstream activities such as exploration and discovery, production operations such as drilling for and transport of crude oil and gas. Downstream operations include: refining the crude oil to produce a range of products such as LPG, Petrol, Kerosene and jet fuel, Diesel fuel an residual products for the chemical industry (i.e. hydro carbons for polymer products); Distribution operations including pipeline operations and haulage; Marketing activities for Wholesale, Retail and Lubricants. The following schematic details the relationships between these operations.



b) The factors that affect the price of crude oil and many and varied, the best way of depicting these factors is to provide a schematic. It is important to explore the current situation and future expectations. In principle, the price is set by willing buyers and sellers. Each buyer and seller makes his or her own assessment of market value based on many factors such as:

c) The four key processes are:

Distillation: Treatment: Upgrading: Blending.
The core refining process is simple distillation. Because crude oil is made up of a mixture of hydrocarbons, this first and basic refining process is aimed at separating the crude oil into its "fractions," the broad categories of its component hydrocarbons. Crude oil is heated and put into a still -- a distillation column -- and different products boil off and can be recovered at different temperatures. The lighter products -- liquid petroleum gases (LPG), naphtha, and so-called "straight run" gasoline -- are recovered at the lowest temperatures. Middle distillates -- jet fuel, kerosene, distillates (such as home heating oil and diesel fuel) -- come next. Finally, the heaviest products (residuum or residual fuel oil) are recovered, sometimes at temperatures over 1000 degrees F. This process is followed by Treatment operations, e.g. Hydrofiners are introduced to remove impurities such as sulphur and nitrogen.

Additional processing follows crude distillation, "downstream" (or closer to the refinery gate and the consumer) of the distillation process. Downstream processing encompasses a variety of highly complex units designed for very different upgrading processes. Some change the molecular structure of the input with chemical reactions, some in the presence of a catalyst, some with thermal reactions.

In general, these processes are designed to take heavy, low-valued feedstock -- often itself the output from an earlier process -- and change it into lighter, higher-valued output. In the upgrading step, A catalytic cracker, for instance, uses the gasoil (heavy distillate) output from crude distillation as its feedstock and produces additional finished distillates (heating oil and diesel) and gasoline. Sulphur removal is accomplished in a hydrotreater. A reforming unit produces higher octane components for gasoline from lower octane feedstock that was recovered in the distillation process. A coker uses the heaviest output of distillation, the residue or residuum, to produce a lighter feedstock for further processing, as well as petroleum coke.

c) Broadly speaking, refining developed in consuming areas, because it was cheaper to move crude oil than to move product. Furthermore, the proximity to consuming markets made it easier to respond to weather-induced spikes in demand or to gauge seasonal shifts. Thus, while the Middle-East is the largest producing region, the bulk of refining takes place in the United States, Europe or Asia.

There have historically been a few exceptions, concentrations of refining capacity that were not proximate to consuming markets. A refining centre in the Caribbean, for instance, supplied heavy fuel oil to the U.S. East Coast where it was used for power, heat, and electric generation. As the demand for this heavy fuel oil, or residual fuel oil, waned, so did those dedicated refineries. While the Caribbean refineries, as well as refineries in the Middle East and in Singapore, were built for product export, they are the exception. As such, most refineries meet their "local" demand first, with exports providing a temporary flow for balancing supply and demand. In addition the migration of manufacturing industries tends to be linked with high manpower requirements, i.e., lower labour costs which can offset the higher cost of product distribution to the home economies. Refinery plants generally employ relatively small number of workers and are characterised by very high capital and operation costs which tend to be significantly larger than labours costs. Security of energy supply and distribution is another issue facing companies engaged in transferring production operations to low wage economies. It is likely that the refinery operations will not be the subject of large scale global industrial migration.

Examiners Comments

Another popular process industry question with 33 candidates choosing to answer. This question not only tested the candidates technical appreciation of the oil industry it also required a socio-political perspective. In section a, high scoring candidates provided greater details on the technical aspects of the oil industry rather than simple schematic representations. Answers to section b ranged from excellent critiques of the factors that affect the price of crude oil to less developed answers that had limited scope. Few answers gave sufficient detail in section c, with most candidates choosing to list the process steps rather than detail them. The majority of candidates gave comprehensive answers for section d.