4C4 2004 CRMB

1 (a) Use a solution neutral problem statement to describe the overall function of the new packaging. [10%]

"Provide safe dispensing of methotrexate for adult user."

(b) List the key requirements for the new packaging. [20%]

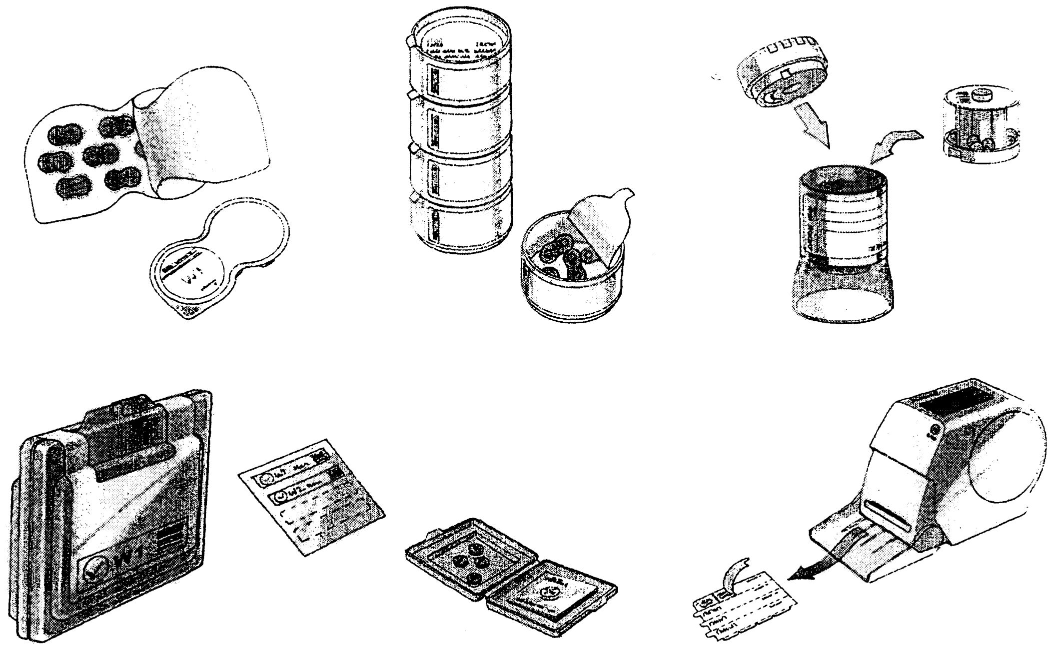
*There are many possible answers here, but the dominant requirements are those that ensure that the **correct** dose is taken **weekly**. Packaging must also be **childproof**, yet possible to open by those with **arthritis**. A system that differentiates on hand size and/or ability to read opening instructions may be appropriate. **Clear** instructions must be provided.*

(c) Define a process function structure for the safe use of methotrexate. [20%]

Steps should include: identify dispenser; identify date; confirm dose; open dispenser; extract dose; close dispenser; take dose.

(d) Identify solution principles for the critical functions identified in (c) and describe a packaging concept that will ensure the safe administration of methotrexate. [50%]

There are many possible concepts. The better one have clear labelling identifying the week/date for taking the medication. Separating weekly doses is also preferred. Dispensers with automatic locks are also possible.



2 (a) Describe the role of *design process models* in design with reference to the key stages found in most process models. [50%]

Reference notes section 1. Key issue is that process models provide a formal structure that helps to ensure that things are not missed. At a high level stages are: design; production; use; and disposal. At a lower level design may be described by: clarification of the task; conceptual design; embodiment design; and detail design.

(b) Describe the role of *evaluation* in design with reference to verification, validation and review activities. [30%]

Reference notes section 10. Key issue is that designs must be proven to be fit for purpose. Validation – check against user need; verification – check against specification; and review – check design activities/evaluation activities.

(c) Describe the role of *risk management* in design. [20%]

Reference notes section 8. Key issue is that of reducing risk throughout the design process. All design activities should strive to reduce the risk of technical or commercial failure of the project.

3 A small mechanical assembly is shown in its assembled and disassembled states in Fig 1. The bush and washer are to be assembled onto the pin and retained in place by the sprung clip. Tolerances on all the components are ± 0.1 mm on all dimensions and all parts are supplied by different manufacturers. The sprung clip has a nominal thickness of 1.0 mm in its compressed state (i.e. it has been manufactured from 1.0 mm sheet) and has a nominal thickness of 2.0 ± 0.5 mm in its manufactured state (i.e. after it has been pressed to form a spring). You should assume that 2σ represents the variation from minimum to maximum dimension on all components.

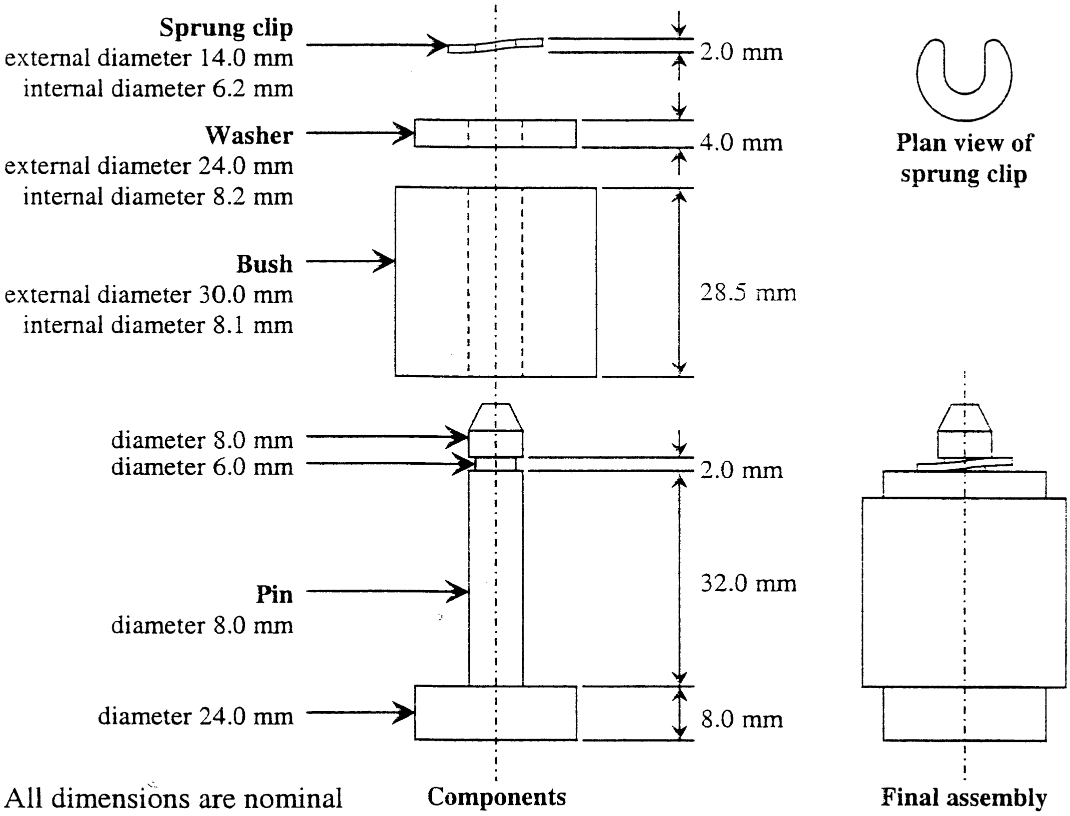


Fig 1.

(a) Draw a fault tree to identify all possible assembly failure modes. [20%]

Top event is device assembly failure. Main contributory failures are: bush does not fit on pin; washer does not fit on pin; clip does not fit on pin (two modes). Incorrect order may be possible, but likelihood can not be predicted. Assembly may also be 'loose'.

(b) Calculate the likely percentage of assemblies that will be able to be assembled correctly. [40%]

The assembly failure modes may be modelled to find probabilities of failure. Dimensional distributions may be assumed to be independent. Rejects are 41%.

Initial dimensions

		bush/pin	washer/pin	clip/pin	bush+washer/pin
dimension 1	mean	8.10	8.20	6.20	34.00
	deviation	0.10	0.10	0.10	0.14
dimension 2	mean	8.00	8.00	6.00	33.50
	deviation	0.10	0.10	0.10	0.17
difference	mean	0.10	0.20	0.20	0.50
	deviation	0.14	0.14	0.14	0.22
z		-0.707	-1.414	-1.414	-2.236
P(-z)		0.7603	0.9214	0.9214	0.9873
1 - P(-z)		0.2397	0.0786	0.0786	0.0127
%		23.97	7.86	7.86	1.27
sum					40.97

(c) Suggest how changes to the design or improvements to the manufacture of the components could improve this percentage to 99%. Justify your answer. [40%]

Reduction of the pin diameters by 0.25 mm and an increase of the pin height by 0.25 mm result in an acceptable error level. There are many other opions.

Revised dimensions

		bush/pin	washer/pin	clip/pin	bush+washer/pin
dimension 1	mean	8.10	8.20	6.20	34.25
	deviation	0.10	0.10	0.10	0.14
dimension 2	mean	7.75	7.75	5.75	33.50
	deviation	0.10	0.10	0.10	0.17
difference	mean	0.35	0.45	0.45	0.75
	deviation	0.14	0.14	0.14	0.22
z		-2.475	-3.182	-3.182	-3.354
P(-z)		0.9933	0.9993	0.9993	0.9996
1 - P(-z)		0.0067	0.0007	0.0007	0.0004
%		0.67	0.07	0.07	0.04
sum					0.85

a) A formal optimization includes:

- constants - gravity
- parameters - load, material choice => E, ρ
  length of each beam in model $\underline{l} = \{l_1 \dots l_n\}$
- variables - $\cdot\ \underline{h} = \{h_1 \dots h_n\}$ height of each beam
  $\underline{b} = \{b_1 \dots b_n\}$ width of each beam
- objective function - minimize structural mass

$$\min\ f(\underline{h},\underline{b}) = \sum_{i=1}^{n} \rho b_i h_i l_i$$

- constraints (all constraints written in negative-null form)

$$\text{s.t.}\quad \underline{\delta} < \delta_{max} \qquad \text{max displacement}$$

$$\left.\begin{array}{l} \underline{b} < b_{max} \\ \underline{h} < h_{max} \\ \forall n\ \ b_{min} - b_n \leq 0 \\ \forall n\ \ h_{min} - h_n \leq 0 \end{array}\right\} \text{space / manufacturing consideration}$$

$$\forall n\ \ h_n \geq b_n \quad \text{(optional - to keep major axis assumption)}$$

Assumptions: joint weight not affected by cross-section
any cross-section within bounds can be fabricated
displacement constraint dominates structural behavior

b) If convex => Hessian positive-definite

$f(b,h) = \rho b h l$ (2 variables b & h)

$$\frac{\partial f}{\partial b} = \rho h l \qquad \frac{\partial f}{\partial h} = \rho b l$$

$$H = \begin{bmatrix} 0 & \rho l \\ \rho l & 0 \end{bmatrix} \qquad |0| = 0 \qquad \begin{vmatrix} 0 & \rho l \\ \rho l & 0 \end{vmatrix} = -(\rho l)^2$$

since zero & negative => negative-semidefinite
$\therefore$ NOT pos-def
$\therefore$ NOT convex

Newton's Method:

$$\underline{x}_{k+1} = \underline{x}_k - H(x_k)^{-1}\nabla f(x_k)$$

For this function H is constant so $H(x_k) = \mathbb{H}$.

$$\underline{x}_0 = \begin{pmatrix} b \\ h \end{pmatrix} = \begin{pmatrix} 0.01 \\ 0.01 \end{pmatrix}$$

$$H^{-1} = \begin{bmatrix} 0 & 1/\rho l \\ 1/\rho l & 0 \end{bmatrix}. \qquad \nabla f(\underline{x}_0) = \begin{pmatrix} 0.01\rho l \\ 0.01\rho l \end{pmatrix}$$

So,

$$\underline{x}_1 = \begin{pmatrix} 0.01 \\ 0.01 \end{pmatrix} - \begin{bmatrix} 0 & 1/\rho l \\ 1/\rho l & 0 \end{bmatrix}\begin{pmatrix} 0.01\rho l \\ 0.01\rho l \end{pmatrix} = \begin{pmatrix} 0.01 \\ 0.01 \end{pmatrix} - \begin{pmatrix} 0.01 \\ 0.01 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

- For this function H is constant since the objective function is a quadratic and so the approximation made in Newton's method is exact => convergence in one step.
- The point is not a global optima since the function is not convex.

c)

$$\min \quad \rho b h l$$

$$\text{s.t.} \quad \delta \leq \delta_{max} = \frac{5 W l^3}{384 E I}$$

$$I = \frac{bh^3}{12}$$

$E_{steel} = 210\,GPa$ (structures d.b.)

$\rho_{steel} = 7850\ kg/m^3$ (structures d.b.)

$l = 1m$

$W = 3kN/m \cdot 1m = 3kN$

If constraint active at optimum =>

$$\delta = \delta_{max} = \frac{5 \cdot 3000\cancel{N} \cdot (1m)^3}{384 \cdot 2.10 \cdot 10^{11} \cancel{Pa} \cdot \frac{bh^3}{12}}$$

$$0.001m = \frac{2.232 \cdot 10^{-9}}{bh^3}\ m$$

for $b = 0.01m$ => $h \simeq 0.060666$ => $\rho b h l \simeq 4.76\ kg$

A constraint on $b_{min} = 0.01\,m$ must exist and be active since if we could decrease b we could decrease h while still meeting the constraint and reducing the mass. Thus "active" constraints influence the location of the optima

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