NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF INDUSTRIAL TECHNOLOGY

DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING

B-Eng Hons Industrial and Manufacturing Engineering

2nd Semester Main Examination

COURSE : Manufacturing Engineering Design
CODE : TIE 3220
DATE : April/May 2014
DURATION : 3 Hours

INSTRUCTIONS AND INFORMATION FOR THE CANDIDATE

1. Answer any **five (5) questions**.
2. All questions carry **20 marks** each.
3. This paper contains **seven (7)** questions.
4. There are **thirteen (13)** printed pages.
5. List of formulae is attached in Appendix A at the end of the question paper.

QUESTION 1

a) There are two broad classes of polymeric material available for polymer processing – thermoplastics and thermosets. For the two types highlight the following:

i) The characteristics of the polymer. [2,4]

ii) Common product applications. [4]

iii) Types of polymer processing applicable. [4]

b) Figure Q1 shows the sectional view of two proposed alternative designs for an injection-molded box shaped part that is enclosed on four sides. From the point of view of tooling costs, which of the two designs is most costly? Assume that the wall thickness is the same in all designs. [6]

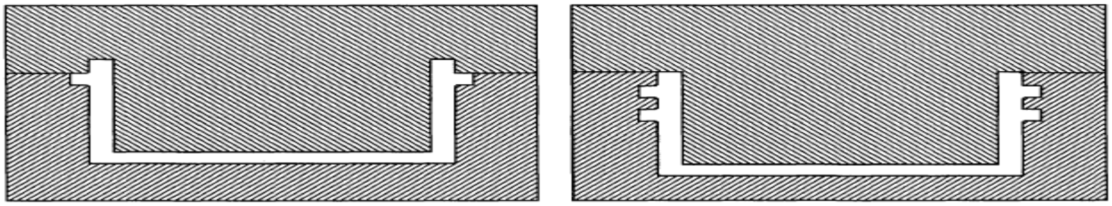


Figure Q1

QUESTION 2

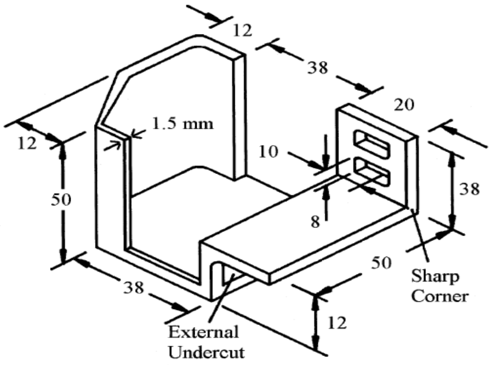
a) There are four types of ribs that can be used in Injection molded parts.

   i) Name the four types of ribs. [4]

   ii) Describe the effects they have on the cycle time. [2]

   iii) Explain two (2) ways in which the sink marks due to ribs can be avoided. [4]

b) You are part of the design team at Kotek Engineering. You have been asked to roughly estimate the cycle time for the part shown in Figure Q2 if it is produced with commercial tolerances. What would you estimate the the cycle time to be if the part is made of nylon 6 in a mold with an SPI finish of 3. The maximum wall thickness of the part is 2.5mm. The minimum wall thickness is 1.5mm.



Notes: 1. All dimensions in mm.
2. Part thickness is 2.5 mm except where noted.

Figure Q2

QUESTION 3

a) Discuss the following types of metal casting methods, in each highlighting the method, types of metals which can be used for the particular type, part types that can be produced.
   - i) Sand casting [3,1,1]
   - ii) Investment Casting. [3,1,1]

b) Explain five DFM guidelines for casting. [10]

QUESTION 4

a) The stamping process can be divided into two broad categories. Using appropriate diagrams distinguish the two categories. [6]

b) The part shown in Figure Q4 is made of soft cold rolled steel. The location of the holes A and C are not critical. Distortion of hole B is not permitted. Determine:
   - i) The relative die construction cost for the part. [6]
   - ii) The relative die material cost for the part. [6]
   - iii) The overall die cost for the part. [2]

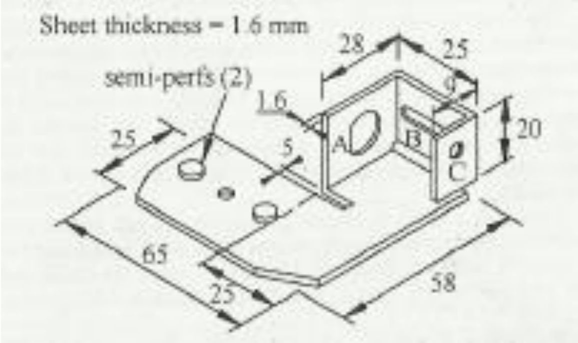


Fig Q4

QUESTION 5

a) Use Fig Q5 to answer the following questions;

   i) Use an appropriate algorithm to deduce the number of active stations required to produce the part. [4]
   ii) There are two possible layouts for developing the strip for the part. Show these two possibilities by means of clear sketches. [2]
   iii) Choose one possible layout and complete the strip development process. [8]

b) Define using diagrams the following terms commonly used in the construction of dies.
   i) Internal undercuts [3]
   ii) External undercuts [3]

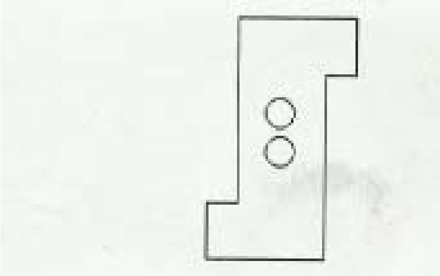


Figure Q5

QUESTION 6

a) For a production volume of 40 000 parts, given that: Shear strength σ- 306MPa, A- 48.2inches, Feff – 0.75, tsetup – 1hr, $t_{\circ}$- 0.234, $V_{\circ}$ - 3750mm³, Cmr – 1.00 and Cd – 3.49 for the part shown in Fig Q4 in question 4. Assume it is made of soft cold rolled steel. Determine:
   (i) the relative processing cost, [8]
   (ii) relative material cost and [2]
   (iii) Total relative part cost [2]

b) As part of BJ Tool and DIE you are to give a talk to a design class that is involved in the design of a product that contains a substantial number of stamped parts. As part of your talk you decide to focus on the design of the parts as it affects tooling cost.

   i) Explain why you decide to focus on tooling cost as opposed to material or processing cost? [4]
   ii) Explain in detail exactly which features of the part affect tooling cost. [4]

QUESTION 7

a) Briefly explain four aspects in the design for manufacturing guidelines for stamped parts. [8]

b) For the stamping shown in Fig Q7 what are the redesign suggestions that you can make to help reduce the cost to stamp the part. [6]

c) Explain in the detail the 6 rules of thumb that should be followed in order to produce a good strip layout. [6]

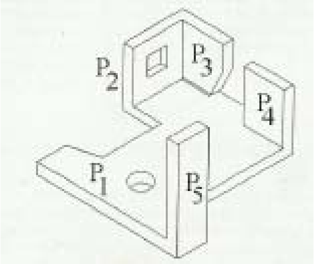
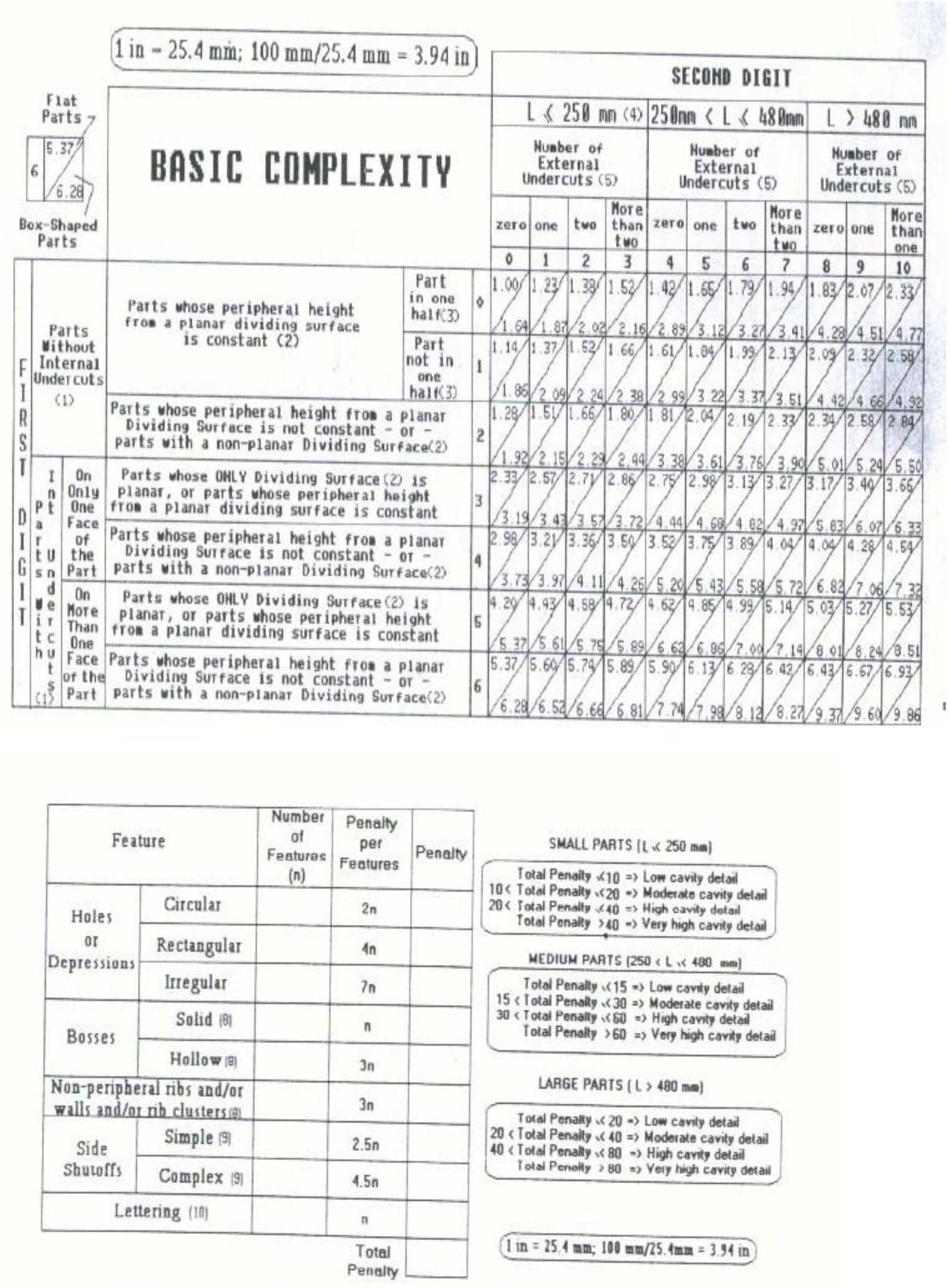


Table Q7

End of Exam

APPENDIX A: A LIST OF FORMULAE FOR INJECTION MOLDING



1 in - 25.4 mm; 100 mm/25.4 mm = 3.94 in

Flat Parts
6 | 5.37 / 6.28
Box-Shaped Parts

		BASIC COMPLEXITY			SECOND DIGIT										
					L ⩽ 250 mm (4)				250mm < L ⩽ 480mm				L > 480 mm		
					Number of External Undercuts (5)				Number of External Undercuts (5)				Number of External Undercuts (5)		
					zero	one	two	More than two	zero	one	two	More than two	zero	one	More than one
					0	1	2	3	4	5	6	7	8	9	10
FIRST DIGIT	Parts Without Internal Undercuts (1)	Parts whose peripheral height from a planar dividing surface is constant (2)	Part in one half(3)	0	1.00 / 1.64	1.23 / 1.87	1.38 / 2.02	1.52 / 2.16	1.42 / 2.89	1.65 / 3.12	1.79 / 3.27	1.94 / 3.41	1.83 / 4.28	2.07 / 4.51	2.33 / 4.77
			Part not in one half(3)	1	1.14 / 1.86	1.37 / 2.09	1.52 / 2.24	1.66 / 2.38	1.61 / 2.99	1.84 / 3.22	1.99 / 3.37	2.13 / 3.51	2.09 / 4.42	2.32 / 4.66	2.58 / 4.92
		Parts whose peripheral height from a planar Dividing Surface is not constant - or - parts with a non-planar Dividing Surface(2)		2	1.28 / 1.92	1.51 / 2.15	1.66 / 2.29	1.80 / 2.44	1.81 / 3.38	2.04 / 3.61	2.19 / 3.76	2.33 / 3.90	2.34 / 5.01	2.58 / 5.24	2.84 / 5.50
	Parts With Internal Undercuts (1) On Only One Face of the Part	Parts whose ONLY Dividing Surface (2) is planar, or parts whose peripheral height from a planar dividing surface is constant		3	2.33 / 3.19	2.57 / 3.43	2.71 / 3.57	2.86 / 3.72	2.75 / 4.44	2.98 / 4.68	3.13 / 4.82	3.27 / 4.97	3.17 / 5.83	3.40 / 6.07	3.66 / 6.33
		Parts whose peripheral height from a planar Dividing Surface is not constant - or - parts with a non-planar Dividing Surface(2)		4	2.98 / 3.73	3.21 / 3.97	3.36 / 4.11	3.50 / 4.26	3.52 / 5.20	3.75 / 5.43	3.89 / 5.58	4.04 / 5.72	4.04 / 6.82	4.28 / 7.06	4.54 / 7.32
	Parts With Internal Undercuts (1) On More Than One Face of the Part	Parts whose ONLY Dividing Surface (2) is planar, or parts whose peripheral height from a planar dividing surface is constant		5	4.20 / 5.37	4.43 / 5.61	4.58 / 5.75	4.72 / 5.89	4.62 / 6.62	4.85 / 6.86	4.99 / 7.00	5.14 / 7.14	5.03 / 8.01	5.27 / 8.24	5.53 / 8.51
		Parts whose peripheral height from a planar Dividing Surface is not constant - or - parts with a non-planar Dividing Surface(2)		6	5.37 / 6.28	5.60 / 6.52	5.74 / 6.66	5.89 / 6.81	5.90 / 7.74	6.13 / 7.98	6.28 / 8.12	6.42 / 8.27	6.43 / 9.37	6.67 / 9.60	6.93 / 9.86

Feature		Number of Features (n)	Penalty per Features	Penalty
Holes or Depressions	Circular		2n	
	Rectangular		4n	
	Irregular		7n	
Bosses	Solid (8)		n	
	Hollow (8)		3n	
Non-peripheral ribs and/or walls and/or rib clusters (8)			3n	
Side Shutoffs	Simple (9)		2.5n	
	Complex (9)		4.5n	
Lettering (10)			n	
			Total Penalty	

SMALL PARTS (L ⩽ 250 mm)

Total Penalty ⩽10 => Low cavity detail
10< Total Penalty ⩽20 => Moderate cavity detail
20< Total Penalty ⩽40 => High cavity detail
Total Penalty >40 => Very high cavity detail

MEDIUM PARTS (250 < L ⩽ 480 mm)

Total Penalty ⩽15 => Low cavity detail
15 < Total Penalty ⩽30 => Moderate cavity detail
30 < Total Penalty ⩽60 => High cavity detail
Total Penalty >60 => Very high cavity detail

LARGE PARTS (L > 480 mm)

Total Penalty ⩽ 20 => Low cavity detail
20 < Total Penalty ⩽ 40 => Moderate cavity detail
40 < Total Penalty ⩽ 80 => High cavity detail
Total Penalty > 80 => Very high cavity detail

1 in = 25.4 mm; 100 mm/25.4mm = 3.94 in

FIGURE 4.19 *Determination of cavity detail. (The numbers in parentheses refer to notes found in Appendix 4.A.)*

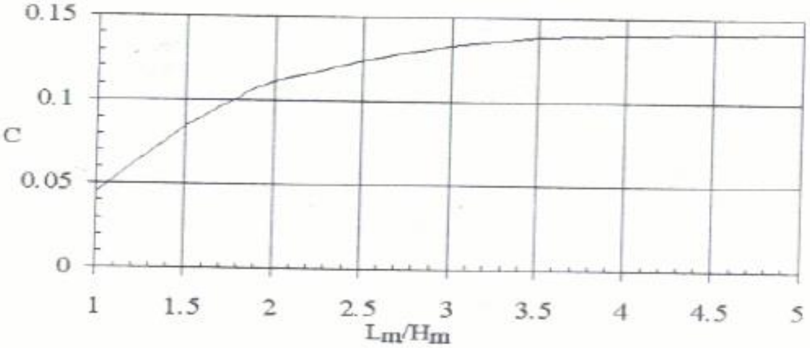


FIGURE 4.23 *Value of C for use in Equation 4.6. (If L_m/H_m <1, then use the value of H_m/L_m to determine C.)*

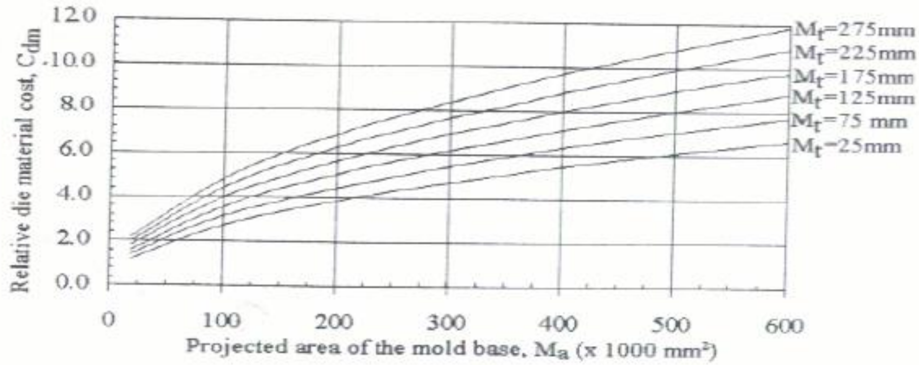


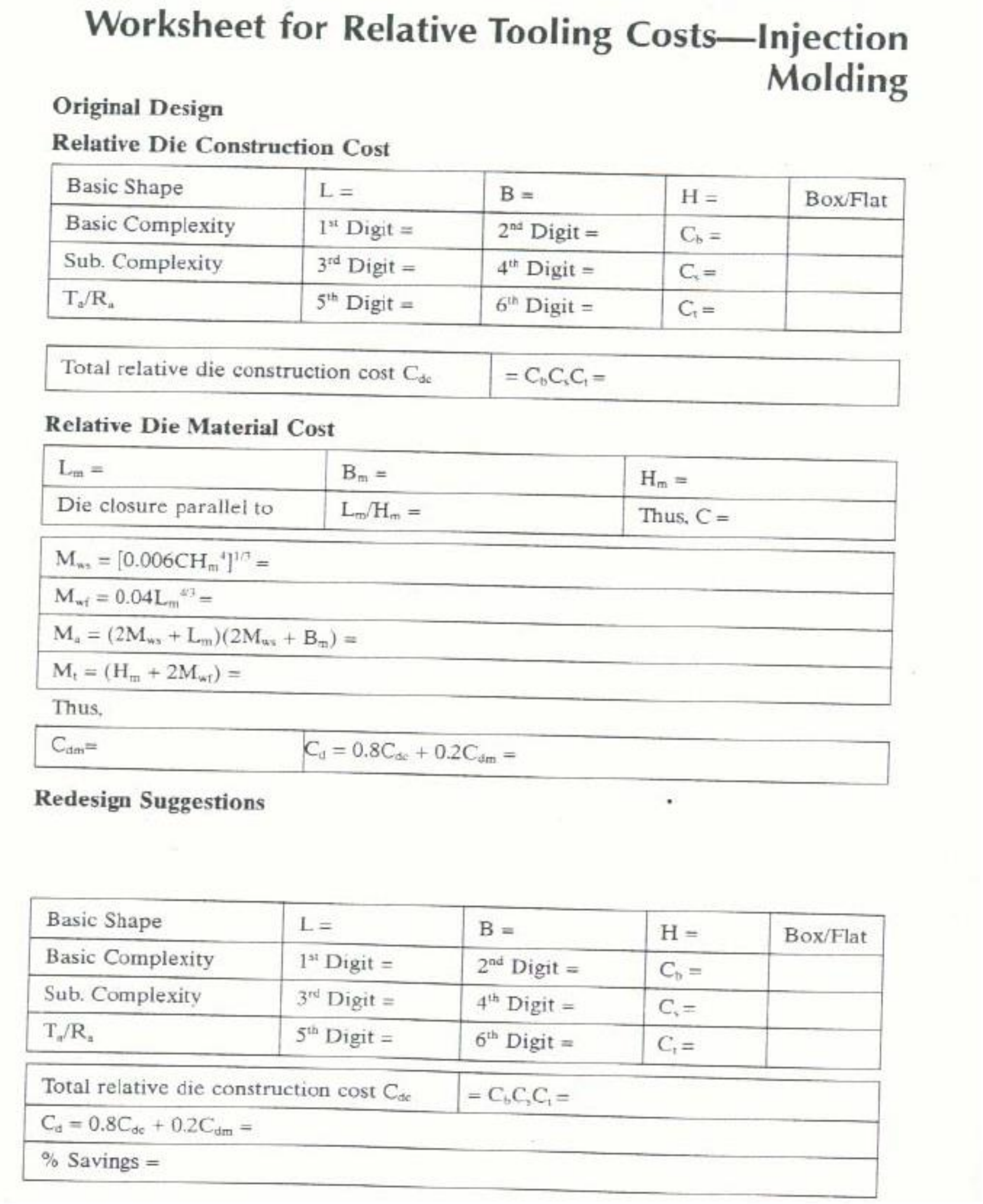
FIGURE 4.24 *Relative die material cost.*

Table 4.1 Subsidiary complexity rating, C_s. (The numbers in parentheses refer to notes found in Appendix 4.A.)

				Fourth Digit	
				Without Extensive (7) External Undercuts (5)	With Extensive (7) External Undercuts (5)
				0	1
Third Digit	Cavity Detail (6)	Low	0	1.00	1.25
		Moderate	1	1.25	1.45
		High	2	1.60	1.75
		Very High	3	2.05	2.15

Table 4.2 Tolerance and surface finish rating, C_t. (The numbers in parentheses refer to notes found in Appendix 4.A.)

				Sixth Digit	
				Commercial Tolerance, T_a	Tight Tolerance, T_a
				0	1
Fifth Digit	Surface Finish, R_a	SPI 5–6	0	—	—
		SPI 3–4	1	1.00	1.05
		Texture	2	1.05	1.10
		SPI 1–2	3	1.10	1.15



Worksheet for Relative Tooling Costs—Injection Molding

Original Design

Relative Die Construction Cost

Basic Shape	L =	B =	H =	Box/Flat
Basic Complexity	1st Digit =	2nd Digit =	C_b =	
Sub. Complexity	3rd Digit =	4th Digit =	C_s =	
T_a/R_a	5th Digit =	6th Digit =	C_t =	

Total relative die construction cost C_{dc}	$= C_bC_sC_t =$

Relative Die Material Cost

L_m =	B_m =	H_m =
Die closure parallel to	L_m/H_m =	Thus, C =

$M_{ws} = [0.006CH_m^4]^{1/3} =$

$M_{wf} = 0.04L_m^{4/3} =$

$M_a = (2M_{ws} + L_m)(2M_{ws} + B_m) =$

$M_t = (H_m + 2M_{wf}) =$

Thus,

C_{dm}=	$C_d = 0.8C_{dc} + 0.2C_{dm} =$

Redesign Suggestions

Basic Shape	L =	B =	H =	Box/Flat
Basic Complexity	1st Digit =	2nd Digit =	C_b =	
Sub. Complexity	3rd Digit =	4th Digit =	C_s =	
T_a/R_a	5th Digit =	6th Digit =	C_t =	

Total relative die construction cost C_{dc}	$= C_bC_sC_t =$
$C_d = 0.8C_{dc} + 0.2C_{dm} =$	
% Savings =	

SECOND DIGIT

Wall Thickness

FIRST DIGIT

(a) Slender Partitionable Parts, S

				$w < 1$ mm	$1\text{mm} \leq w \leq 2\text{mm}$	$2\text{mm} < w \leq 3\text{mm}$	$3\text{mm} < w \leq 4\text{mm}$	$4\text{mm} < w \leq 5\text{mm}$	$w > 5\text{mm}$
				0	1	2	3	4	5
Parts with $L_u/B_u \geq 10$ (1) or Frames (2)	Plates with $L_u/2w < 100$ (3) without lateral projections (4)	Without ribs	0	Difficult to fill or eject	1.00	1.35	1.70	2.55	Use foamed materials (9)
		With ribs	1		1.10	1.45	1.85	2.70	
	Plates with $L_u/2w \geq 100$ and/or plates with lateral projections (4)	Without ribs	2		1.15	1.55	2.00	2.85	
		With ribs	3		1.25	1.82	2.20	3.85	

(b) Non-Slender Partitonable Parts, N

					$w < 1$ mm	$1\text{mm} \leq w \leq 2\text{mm}$	$2\text{mm} < w \leq 3\text{mm}$	$3\text{mm} < w \leq 4\text{mm}$	$4\text{mm} < w \leq 5\text{mm}$	$w > 5\text{mm}$
					0	1	2	3	4	5
Parts with $\frac{L_u}{B_u} \leq 10$ (1)	Plates without significant rib (5) or significant bosses (6) with or without non-peripheral ribs or bosses	Plates which are grilled or slotted (7)	Without non-peripheral ribs	0	Difficult to fill or eject	1.68	2.39	3.11	3.82	Use foamed materials (9)
			With non-peripheral ribs	1		1.82	2.53	3.25	3.96	
		Plates which are not grilled or slotted (7)	Without non-peripheral ribs	2		1.96	2.67	3.39	4.10	
			With concentric or cross ribbing	3		2.10	2.81	3.53	4.24	
			With radial or unidirectional ribbing	4		2.24	2.96	3.67	4.39	
	Plates with significant ribs (5) and/or significant bosses (6)	Plates with rib and/or boss thickness less than the wall thickness (8)	Ribs/bosses supported by gusset plates	5		2.38	3.10	3.81	4.53	
			Ribs/bosses not supported by gusset plates	6		2.52	3.24	3.95	4.67	
		Plates with rib and/or boss thicknes (8) greater than or equal to the wall thickness		7		2.66	3.38	4.09	4.81	

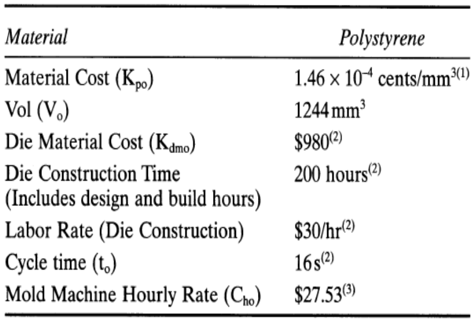
(c) Non-Partitionable Parts

			$w < 1$ mm	$1\text{mm} \leq w \leq 2\text{mm}$	$2\text{mm} < w \leq 3\text{mm}$	$3\text{mm} < w \leq 4\text{mm}$	$4\text{mm} < w \leq 5\text{mm}$	$w > 5\text{mm}$
			0	1	2	3	4	5
Parts which are not partitionable	Easy to cool (10)	0	Difficult to fill or eject	2.66	3.38	4.09	4.81	Use Foamed Materials
	Difficult to cool (10)	1		3,56	4.50	5.47	6.40	

1 in = 25.4 mm; 1 mm/25.4 mm = 0.04 in

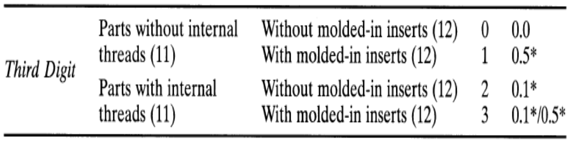
FIGURE 5.2 *Classification system for basic relative cycle time, t_b. (The numbers in parentheses refer to notes found in Appendix 5.A.)*

Table 5.1 Data for the reference part.



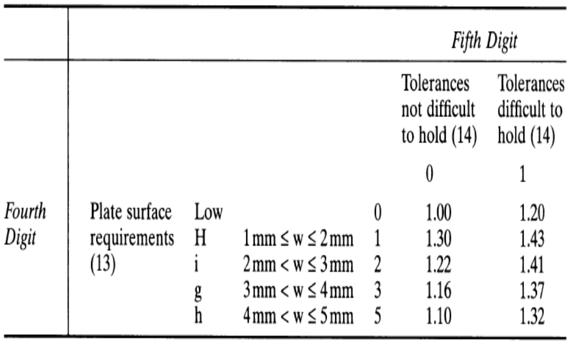
Material	*Polystyrene*
Material Cost (K_{po})	1.46×10^{-4} cents/mm$^{3(1)}$
Vol (V_o)	1244 mm^3
Die Material Cost (K_{dmo})	\$980$^{(2)}$
Die Construction Time (Includes design and build hours)	200 hours$^{(2)}$
Labor Rate (Die Construction)	\$30/hr$^{(2)}$
Cycle time (t_o)	16 s$^{(2)}$
Mold Machine Hourly Rate (C_{ho})	\$27.53$^{(3)}$

Table 5.3 Additional relative time, t_e, due to inserts and internal threads. (The numbers in parentheses refer to notes found in Appendix 5.A.)



Third Digit	Parts without internal threads (11)	Without molded-in inserts (12)	0	0.0
		With molded-in inserts (12)	1	0.5*
	Parts with internal threads (11)	Without molded-in inserts (12)	2	0.1*
		With molded-in inserts (12)	3	0.1*/0.5*

Table 5.4 Time penalty, t_p, due to surface requirements and tolerances. (The numbers in parentheses refer to notes found in Appendix 5.A.)



					Fifth Digit	
					Tolerances not difficult to hold (14)	Tolerances difficult to hold (14)
					0	1
Fourth Digit	Plate surface requirements (13)	Low		0	1.00	1.20
		H	$1\,\text{mm} \le w \le 2\,\text{mm}$	1	1.30	1.43
		i	$2\,\text{mm} < w \le 3\,\text{mm}$	2	1.22	1.41
		g	$3\,\text{mm} < w \le 4\,\text{mm}$	3	1.16	1.37
		h	$4\,\text{mm} < w \le 5\,\text{mm}$	5	1.10	1.32

Worksheet for Relative Processing Cost and Total Relative Cost

Original Design/Redesign

$L_u =$	$B_u =$	$L_u/B_u =$	Slender/ Non-slender?	

Basic Relative Cycle Time

	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5
Ext/Int					
1st Digit					
2nd Digit					
t_b					

Additional Time

3rd Digit					
t_e					

Time Penalty

4th Digit					
5th Digit					
t_p					

Relative Cycle Time for Plate

$t_r = (t_b + t_e)t_p$					
Relative Cycle Time for the part =					

Relative Processing Cost

$A_p =$	$F_p =$	$C_{hr} =$	$C_e = t_r C_{hr} =$

Relative Material Cost

$V =$	$V_o =$	$C_{mr} =$	$C_m = (V/V_o)C_{mr} =$

Total Relative Cost

$N =$
$C_r = 0.00182C_m + (6980/N)C_d + 0.1224C_e$

Appendix for Stamping Parts

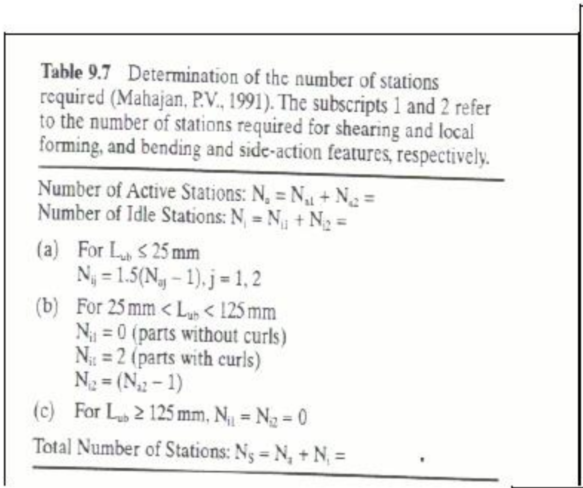


Table 9.7 Determination of the number of stations required (Mahajan, P.V., 1991). The subscripts 1 and 2 refer to the number of stations required for shearing and local forming, and bending and side-action features, respectively.

Number of Active Stations: $N_a = N_{a1} + N_{a2} =$

Number of Idle Stations: $N_i = N_{i1} + N_{i2} =$

(a) For $L_{ub} \leq 25\,\text{mm}$

$N_{ij} = 1.5(N_{aj} - 1), j = 1, 2$

(b) For $25\,\text{mm} < L_{ub} < 125\,\text{mm}$

$N_{i1} = 0$ (parts without curls)

$N_{i1} = 2$ (parts with curls)

$N_{i2} = (N_{a2} - 1)$

(c) For $L_{ub} \geq 125\,\text{mm}$, $N_{i1} = N_{i2} = 0$

Total Number of Stations: $N_S = N_a + N_i =$

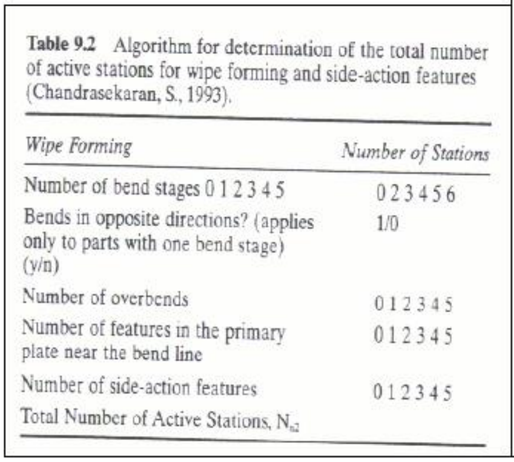


Table 9.2 Algorithm for determination of the total number of active stations for wipe forming and side-action features (Chandrasekaran, S., 1993).

Wipe Forming	*Number of Stations*
Number of bend stages 0 1 2 3 4 5	0 2 3 4 5 6
Bends in opposite directions? (applies only to parts with one bend stage) (y/n)	1/0
Number of overbends	0 1 2 3 4 5
Number of features in the primary plate near the bend line	0 1 2 3 4 5
Number of side-action features	0 1 2 3 4 5
Total Number of Active Stations, N_{a2}	

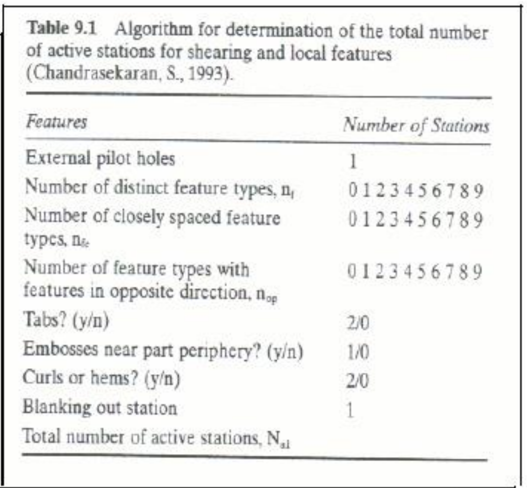


Table 9.1 Algorithm for determination of the total number of active stations for shearing and local features (Chandrasekaran, S., 1993).

Features	*Number of Stations*
External pilot holes	1
Number of distinct feature types, n_f	0 1 2 3 4 5 6 7 8 9
Number of closely spaced feature types, n_{fc}	0 1 2 3 4 5 6 7 8 9
Number of feature types with features in opposite direction, n_{op}	0 1 2 3 4 5 6 7 8 9
Tabs? (y/n)	2/0
Embosses near part periphery? (y/n)	1/0
Curls or hems? (y/n)	2/0
Blanking out station	1
Total number of active stations, N_{a1}	

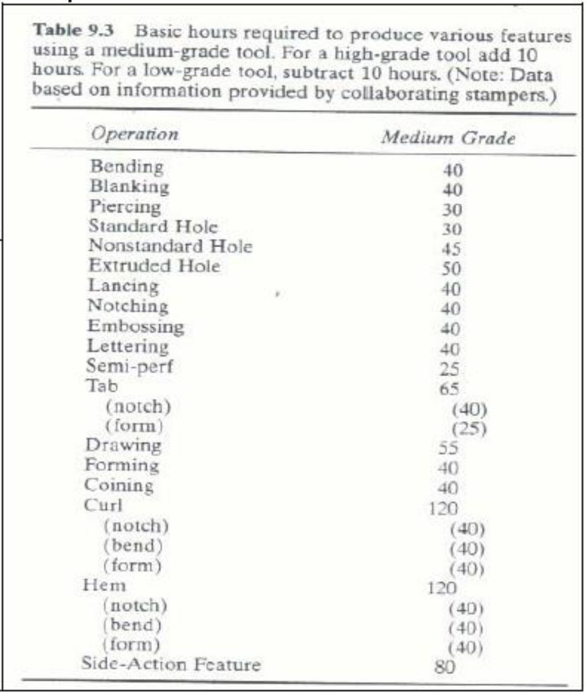


Table 9.3 Basic hours required to produce various features using a medium-grade tool. For a high-grade tool add 10 hours. For a low-grade tool, subtract 10 hours. (Note: Data based on information provided by collaborating stampers.)

Operation	*Medium Grade*
Bending	40
Blanking	40
Piercing	30
Standard Hole	30
Nonstandard Hole	45
Extruded Hole	50
Lancing	40
Notching	40
Embossing	40
Lettering	40
Semi-perf	25
Tab	65
(notch)	(40)
(form)	(25)
Drawing	55
Forming	40
Coining	40
Curl	120
(notch)	(40)
(bend)	(40)
(form)	(40)
Hem	120
(notch)	(40)
(bend)	(40)
(form)	(40)
Side-Action Feature	80

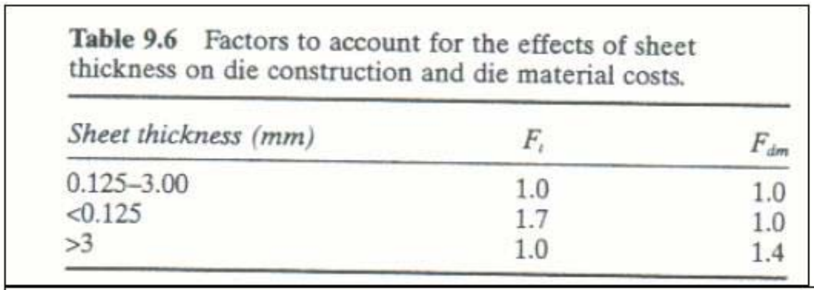
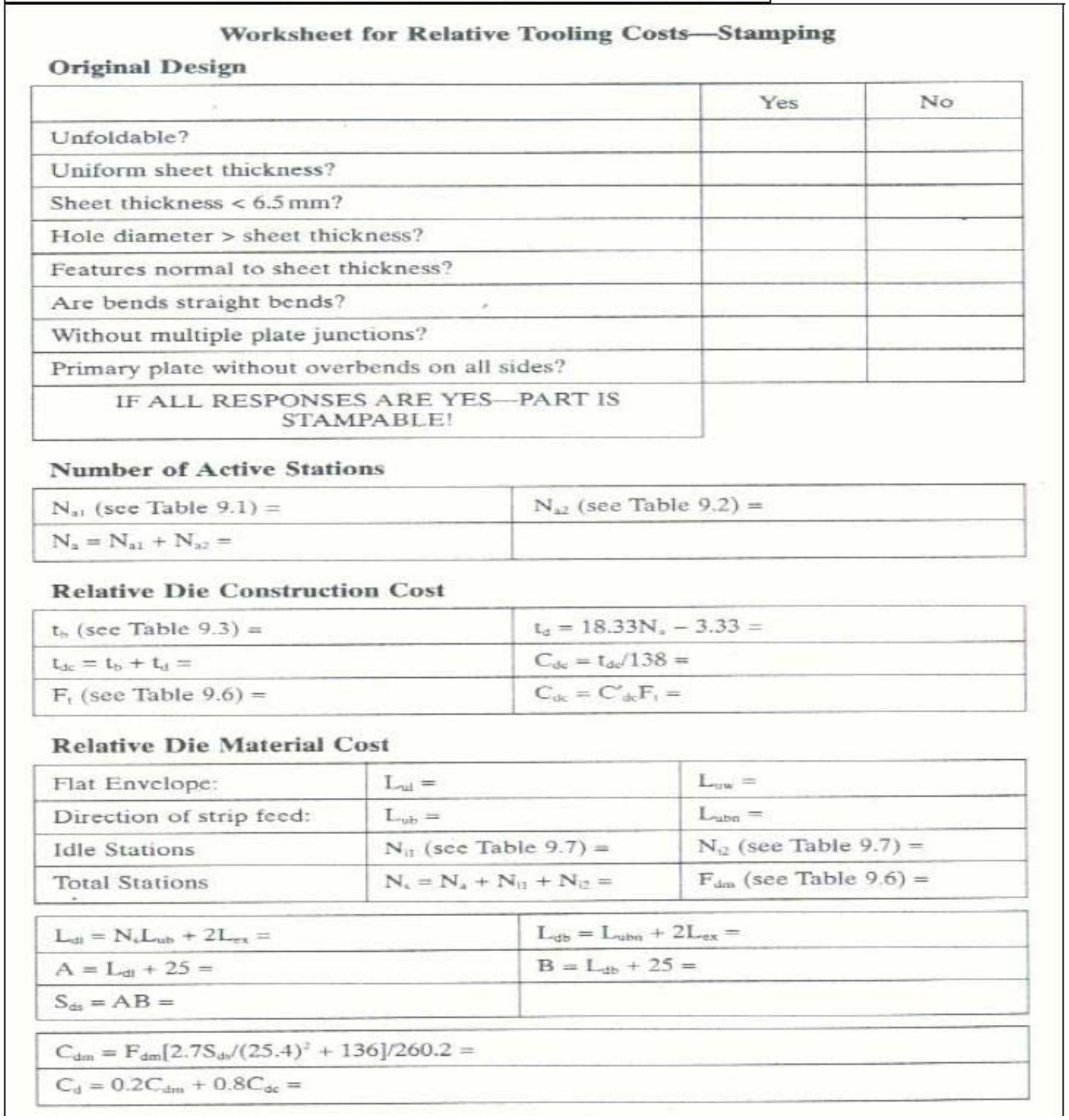


Table 9.6 Factors to account for the effects of sheet thickness on die construction and die material costs.

Sheet thickness (mm)	F_t	F_{dm}
0.125–3.00	1.0	1.0
<0.125	1.7	1.0
>3	1.0	1.4



Worksheet for Relative Tooling Costs—Stamping

Original Design

	Yes	No
Unfoldable?		
Uniform sheet thickness?		
Sheet thickness < 6.5 mm?		
Hole diameter > sheet thickness?		
Features normal to sheet thickness?		
Are bends straight bends?		
Without multiple plate junctions?		
Primary plate without overbends on all sides?		

IF ALL RESPONSES ARE YES—PART IS STAMPABLE!

Number of Active Stations

N_{a1} (see Table 9.1) =	N_{a2} (see Table 9.2) =
$N_a = N_{a1} + N_{a2} =$	

Relative Die Construction Cost

t_b (see Table 9.3) =	$t_d = 18.33N_a - 3.33 =$
$t_{dc} = t_b + t_d =$	$C_{dc} = t_{dc}/138 =$
F_t (see Table 9.6) =	$C_{dc} = C'_{dc}F_t =$

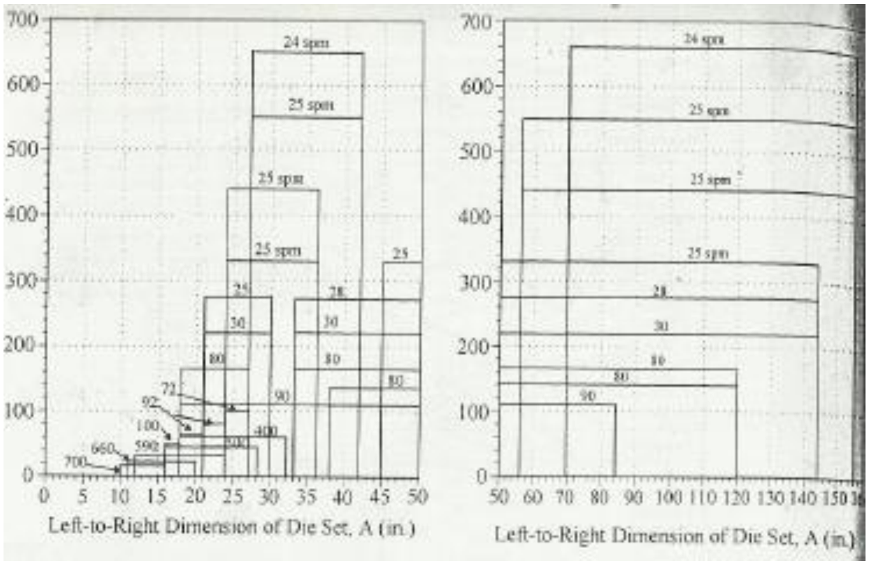
Relative Die Material Cost

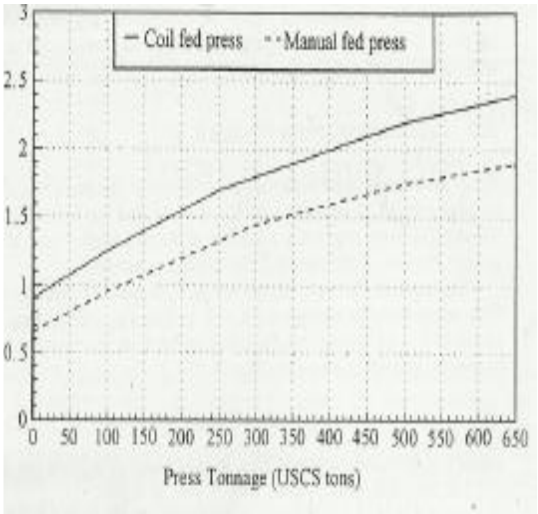
Flat Envelope:	$L_{ul} =$	$L_{uw} =$
Direction of strip feed:	$L_{ub} =$	$L_{ubn} =$
Idle Stations	N_{i1} (see Table 9.7) =	N_{i2} (see Table 9.7) =
Total Stations	$N_t = N_a + N_{i1} + N_{i2} =$	F_{dm} (see Table 9.6) =

$L_{dl} = N_t L_{ub} + 2L_{ex} =$	$L_{db} = L_{ubn} + 2L_{ex} =$
$A = L_{dl} + 25 =$	$B = L_{db} + 25 =$
$S_{ds} = AB =$	

$C_{dm} = F_{dm}[2.7S_{ds}/(25.4)^2 + 136]/260.2 =$

$C_d = 0.2C_{dm} + 0.8C_{dc} =$





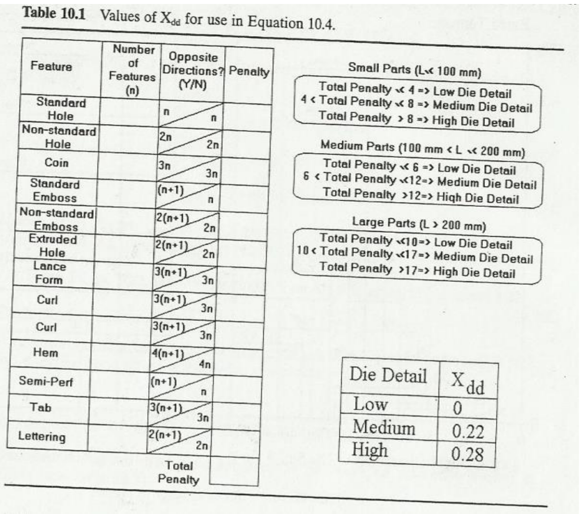


Table 10.1 Values of X_{dd} for use in Equation 10.4.

Feature	Number of Features (n)	Opposite Directions? (Y/N)	Penalty
Standard Hole		n n	
Non-standard Hole		2n 2n	
Coin		3n 3n	
Standard Emboss		(n+1) n	
Non-standard Emboss		2(n+1) 2n	
Extruded Hole		2(n+1) 2n	
Lance Form		3(n+1) 3n	
Curl		3(n+1) 3n	
Curl		3(n+1) 3n	
Hem		4(n+1) 4n	
Semi-Perf		(n+1) n	
Tab		3(n+1) 3n	
Lettering		2(n+1) 2n	
		Total Penalty	

Small Parts (L≤ 100 mm)

Total Penalty ≤ 4 => Low Die Detail
4 < Total Penalty ≤ 8 => Medium Die Detail
Total Penalty > 8 => High Die Detail

Medium Parts (100 mm < L ≤ 200 mm)

Total Penalty ≤ 6 => Low Die Detail
6 < Total Penalty ≤12=> Medium Die Detail
Total Penalty >12=> High Die Detail

Large Parts (L > 200 mm)

Total Penalty ≤10=> Low Die Detail
10 < Total Penalty ≤17=> Medium Die Detail
Total Penalty >17=> High Die Detail

Die Detail	X_{dd}
Low	0
Medium	0.22
High	0.28

Relative Machine Hourly Rate C_{hr}

Worksheet for Relative Processing Costs and Total Relative Cost—Stamping

Original Design/Redesign

Tonnage required (linear dimensions in mm)

Material =	$\sigma_s =$ MPa	$\sigma_t =$ MPa	$L_{out} =$
$t =$	Detail = low/med/high	$X_{dd} =$	$L_{bt} =$

$F_{out} = 1.5L_{out}\sigma_s t =$ kN	$F_{st} = 21L_{out}t =$ kN
$F_s = (F_{out} + F_{st})(1 + X_{dd}) =$	$F_b = \sigma_t L_{bt} t/18 =$ kN
A = inches (from die material calculation)	$F_p = 1.5F = 1.5(F_s+F_b) =$ (Note: 1 ton = 8.89 kN)

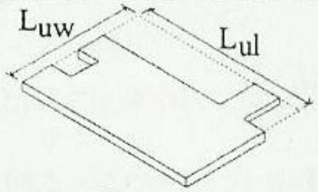
Press Selection (See Figure 10.1)

Tons =	SPM =	$C_{hr} =$ (See Figure 10.2)

Relative Processing Cost

N	$t_{cy} = 3600[1/F_{eff}(60SPM) + 1/N]$	$t_r = t_{cy}/0.234$	$C_e = t_r C_{hr}$

Relative Material Cost

$C_{mr} =$ (See Table 10.2)	 Flat Envelope
$C_m = (V/V_o)C_{mr} =$	$V = L_{ul}L_{uw}t = \text{mm}^3$

Total Relative Part Cost ($C_r = 0.0215C_m + (6561/N)C_d + 0.00177C_e$)

N	C_r