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Assessment of the Factors Affecting Apparel Pattern Grading Accuracy: Problems Identification and Recommendations

Ocena dejavnikov, ki vplivajo na natančnost ocenjevanja gradiranja oblačil: prepoznavanje težav in priporočila

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Abstract
Grading is an inseparable part of producing multiple sized patterns in clothing production. From the inception of apparel manufacturing, various methods have been developed for precision pattern grading. Nevertheless, most conventional grading systems have some flaws. The objectives of this study were to analyse traditional grading systems, identify the factors responsible for pattern grading deficiencies and finally, recommend suggestions to minimise grading problems related to the use of CAD software. For the experiments, three different measurement sheets of different buyers were collected and combined into a single specification for better comparison. All garment patterns were then drawn and graded with varying parameters. Later on, measurements of graded patterns were analysed for grading accuracy. This study presents the factors responsible for grading deficiencies and how they can be minimised for higher precision grading for the better fitting of clothing and the prevention of garment sample rejection before bulk production.
Keywords: grading, CAD, pattern making, grading system, grading problems

Izvleček
Gradiranje je neločljiv del izdelave krojev oblačil različnih velikosti v proizvodnji oblačil. Od začetka industrijske izdelave oblačil so bile razvite različne metode za natančno gradiranje krojev oblačil. Kljub temu pa ima še vedno večina konvencionalnih sistemov gradiranja nekaj pomanjkljivosti. Cilji študije so bili analizirati tradicionalne sisteme gradiranja, ugotoviti dejavnike, ki vplivajo na pomanjkljivosti pri gradiranja krojev oblačil, in na koncu izdelati priporočila za zmanjšanje težav pri gradiranju z uporabo programske opreme CAD. Za eksperimente so bile pridobljene tri specifikacije mer različnih kupcev, združene v eno specifikacijo za lažjo primerjavo. Nato so bili konstruirani vsi krojni deli oblačila in gradirani z različnimi parametri. Kasneje so bile analizirane meritve gradiranih krojnih delov glede natančnosti gradiranja. Študija razkriva dejavnike pomanjkljivosti gradiranja in kako jih je mogoče minimalizirati, da dosežemo večjo natančnost gradiranja za boljše prileganje oblačil in preprečevanje zavrnitve oblačila pred masovno izdelavo.
Ključne besede: gradiranje, CAD, konstruiranje kroja oblačil, sistem gradiranja, problemi gradiranja

1 Introduction

Today's business policy for apparel manufacturers requires quick response systems that turn out a wide variety of products to meet customers' demand. In the apparel industry, in particular, stakeholders are trying to develop their current systems for new production techniques in order to keep pace with the rapid changes in the fashion and clothing industry [1]. The garment production process is separated into four main phases: designing and clothing pattern generation, fabric spreading and cutting, sewing and ironing and packing [2]. In order to manufacture apparel, proper sizing information is mandatory. Sizing is the process used to create a size chart of key body measurements for a range of apparel sizes [3]. For the mass production of ready-to-wear clothing, it is necessary to create all sized garments in the size range or sizes provided in the specification sheet. However, the creation of all size patterns is cumbersome and time-consuming. Pattern grading is traditionally used to create various sizes. Grading is a complex process used to create a complete set of patterns of different sizes contained in the size range. This is done by creating a pattern of a selected base size and then grading it up to create the largest sizes and down to create the smallest sizes. To grade a pattern, a set of grade rules are created or grading increment values are calculated. They are then inserted into the grade or cardinal point. Grade points or cardinal points are those points present at the perimeter of the pattern and distribute the changes in body dimension [4]. Generally, pattern grading is done to increase or decrease the dimension of the pattern to reproduce a complete set of patterns of different sizes in the size range to fit a group of people [5–6]. At present, with the mass the customisation of apparel sizing, advanced computer technology is being used widely [7]. Primarily for quick and precise production in apparel manufacturing, flexible computer-aided manufacturing systems are being applied to apparel manufacturing processes, such as apparel pattern making, grading, and marker making [8–9]. Computer-aided pattern making and grading are based on 2D and 3D CAD technologies. Individual patterns created using basic 2D pattern technologies apply grading and alternation rules [10]. In addition to individual patterns created by 3D CAD technology are 2D patterns that are flattened from a 3D body model, so that they reflect the human body type. However they have practical limitations, including the need to build a new 3D CAD system on the top of the existing apparel manufacturing process [11–13]. For that reason, 2D CAD technology is currently used in the apparel industry primarily for mass customisation. Although the 2D CAD system provides time-saving solutions, the latter are not free from limitations. The grade rule creation or grading increment calculation, which is used by all types of 2D apparel CAD to complete the grading process, is based on manual calculation and inputs [14]. Computerised pattern grading is the most precise and expedient method, but only when an accurate value is entered into the computer [6]. Nevertheless, there are many factors that influence grading and lead to grading deficiencies. The objectives of this study were to identify and analyse the reasons behind the inaccuracy and associated problems, while maintaining the required level of precision in garment pattern grading.

2 Methodology

2.1 Materials

For experiments, three different specification sheets (hereinafter: spec sheets) of different buyers were collected and then combined and drawn to a solitary sketch of a T-shirt (Figure 1 and Table 1), including all points of measures (POM) for the sake of easy comparison. For example, shoulder point can be calculated using three POMs in combination, if any two of "S", "SD and "AS" are given.

Table 1: Measurement points and descriptions of all three specification sheets

2.2 Methods

The patterns of T-shirts of specifications A, B and C were drawn and graded with varying parameters. The measurements of graded patterns were then checked for grading accuracy. The conventional grading system is based on the increment of the given measurement of apparel for different sizes using the Cartesian coordinate values of the grading increment. For example, if high point shoulder is increased by 2 cm, points H and G should increase by 2 cm in the direction of Y. For T-shirt Specs A, B and C, cardinal points represented by A, B, C, E, G, H for front and back and A, B, C, D, E, F, G for sleeve and the Cartesian coordinate values of the grading increment as (X, Y) are shown in Figure 2. The body parts of the three specification sheets have the same grading increment value despite differences in measurement location. In case of the sleeve, however, it is

Table 1: Measurement points and descriptions of all three specification sheets

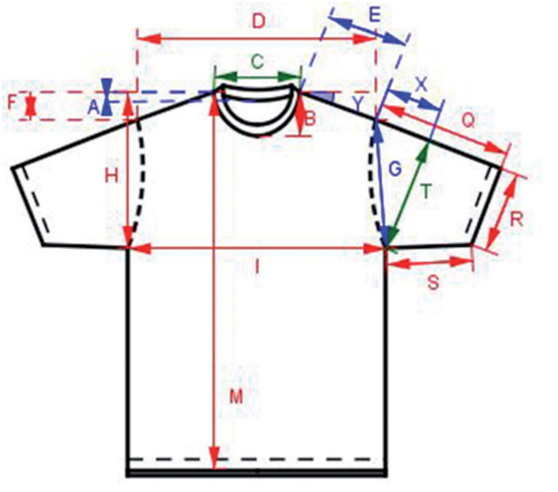


Figure 1: Combination of all measurement points of T-shirt

Points	Description	POMs
A	Back neck drop or depth	BND
B	Front neck drop or depth	FND
C	Neck width or opening	NW
D	Across shoulder width or shoulder to shoulder width	AS
E	Shoulder length	S
F	Shoulder drop or slant	SD
G	Armhole straight	AHS
H	Armscye depth	ASD
I	Half chest girth	HC
M	High point shoulder	HPS
Q	Sleeve length	SL
R	Sleeve opening	SO
S	Under sleeve length	US
T	Sleeve width or upper arm width	SW
X	Sleeve cap height	SCH
Y	Shoulder slant in degree	SSD

POM	Reference spec A					Reference spec B					Reference spec C				
	S	M	L	XL	XXL	S	M	L	XL	XXL	S	M	L	XL	XXL
BND	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FND	8	8.5	9	9.5	10	8	8.5	9	9.5	10	8	8.5	9	9.5	10
NW	16	17	18	19	20	16	17	18	19	20	16	17	18	19	20
AS	-	-	-	-	-	45	48	51	54	57	45	48	51	54	57
S	15	16	17	18	19	15	16	17	18	19	-	-	-	-	-
SD	5	5	5	5	5	-	-	-	-	-	5	5	5	5	5
AHS	24	25	26	27	28	24	25	26	27	28	-	-	-	-	-
ASD	-	-	-	-	-	-	-	-	-	-	29	30	31	32	33
HC	48	51	54	57	60	48	51	54	57	60	48	51	54	57	60
HPS	70	72	74	76	78	70	72	74	76	78	70	72	74	76	78
SL	21	22	23	24	25	21	22	23	24	25	21	22	23	24	25
SO	18	19	20	21	22	18	19	20	21	22	18	19	20	21	22
US	14	14.5	15	15.5	16	-	-	-	-	-	-	-	-	-	-
SW	-	-	-	-	-	23	23.75	24.5	25.25	26	23	23.75	24.5	25.25	26
SCH	-	-	-	-	-	-	-	-	-	-	9.55	10.40	11.25	12.10	12.95

Note: All units are measured in cm. POM: Points of measure

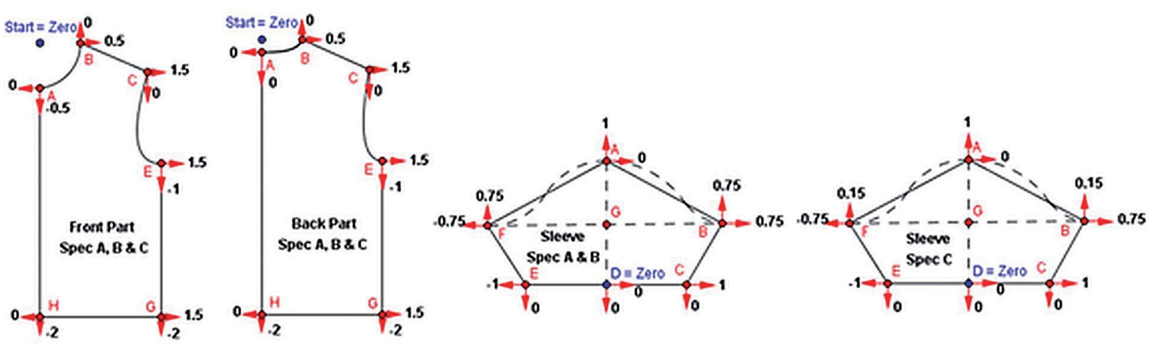


Figure 2: Cardinal points and Cartesian coordinate values of T-shirt spec A, B, and C

important to match the sleeve front and back curve with armhole front and back curve. For both Spec A and B, armhole straight is given, which is a diagonal measurement. In the case of Spec C, however, there are no diagonal measurements. Thus, the impact of the diagonal measurement is explained further in the following sections "presence of diagonal measurement" and "maintaining accuracy and matching of curve line".

2.2.1 Presence of diagonal measurements

Some inclined or diagonal POMs (points of measure) create measurement errors in the traditional XY Cartesian coordinate apparel pattern grading system. In every grading textbook, different authors mention different types of shoulder seam grading [6, 15–18]. There is no consistency on how the textbook authors grade the shoulder [19]. For shoulder seam grading in the conventional method, some assumptions have been used. If across shoulder measurement and shoulder lengths are given (example: Reference Spec C), the X-axis increment is the change in half across shoulder and the Y-axis increment is the change in the shoulder length measurement plus the change in half neck width. However, if shoulder length and shoulder drop is given, the X-axis increment is the change in shoulder length plus the change in half neck width and the Y-axis increment is the change in the shoulder drop. It is thus assumed that shoulder length will increase the amount that is increased in the X or Y-axis. According to geometrical rules, however, any diagonal measurement will not increase for the amount of the increase in the X- or Y-axis. An experiment was conducted to check the effect of the diagonal measurement (e.g. shoulder length). For this experiment, patterns of the Spec A were graded using conventional Cartesian coordinate grading from the L size assumed as the base size. Bye et al. (2008) [20] confirmed that size 10 (medium size) was the optimum

Table 2: Length comparisons of Spec A

POMs	Measurement comparison	Size				
		S	M	L*	XL	XXL
Back neck drop	Length required	1.50	1.50	1.50	1.50	1.50
	Length acquired	1.50	1.50	1.50	1.50	1.50
Front neck drop	Length required	8.00	8.50	9.00	9.50	10.00
	Length acquired	8.00	8.50	9.00	9.50	10.00
Neck width	Length required	16.00	17.00	18.00	19.00	20.00
	Length acquired	16.00	17.00	18.00	19.00	20.00
Shoulder length	Length required	15.00	16.00	17.00	18.00	19.00
	Length acquired	15.10	16.05	17.00	17.96	18.92
Shoulder drop	Length required	5.00	5.00	5.00	5.00	5.00
	Length acquired	5.00	5.00	5.00	5.00	5.00
Armhole straight	Length required	24.00	25.00	26.00	27.00	28.00
	Length acquired	24.00	25.00	26.00	27.00	28.00
Sleeve arm hole straight	Length required	25.00	26.00	27.00	28.00	29.00
	Length acquired	25.42	26.21	27.00	27.79	28.58
Half chest	Length required	48.00	51.00	54.00	57.00	60.00
	Length acquired	48.00	51.00	54.00	57.00	60.00
High point shoulder	Length required	70.00	72.00	74.00	76.00	78.00
	Length acquired	70.00	72.00	74.00	76.00	78.00
Sleeve length	Length required	21.00	22.00	23.00	24.00	25.00
	Length acquired	21.00	22.00	23.00	24.00	25.00
Sleeve opening	Length required	18.00	19.00	20.00	21.00	22.00
	Length acquired	18.00	19.00	20.00	21.00	22.00
Under sleeve	Length required	14.00	14.50	15.00	15.50	16.00
	Length acquired	13.75	14.37	15.00	15.65	16.31

*Note: * = Base size, Black = Length required, Blue = Exactly same, Red = Deviation from original measurements. All units are measured in cm. POM: Points of measure.*

base size for grading patterns in the size range of 6–14. Size 10 was selected because a common practice in grading is to select a size approximately in the middle of the size range to be graded.
It can be concluded from Table 2 that all the horizontal and vertical line lengths are the same because they are plotted on the X and Y-axis respectively, as the computerised grading uses Cartesian coordinates. However, variations are found only in diagonal lines grading. Thus, diagonal measurements should be avoided as much as possible in the spec sheet because they cause grading deficiency.

2.2.2 Maintaining accuracy and matching of curve lines

The computer uses Cartesian coordinates where both points have X and Y values. It is therefore always a challenge how much they should move in both directions to get the accurate curve length.
The grading of a straight line is a simple process as the straight is defined by two endpoints in the computer Cartesian coordinates where both the points have X and Y values. So, it is possible to change the grading values (X, Y) in one or both points to get the desired length. However, the curve line grading is a complex process. Generally, the curve line is formed by connecting several points in the Cartesian coordinates location. When grade rules are applied to the endpoints of a curved edge, the program must mathematically determine how each internal curve and control point should move. The results can distort the curve. Again, in order to construct a well-made garment, the matching seam lines should be of the same length and the shape should not be distorted by the graded pattern pieces. During the grading of the curve line, the amount of change in X and Y directions to achieve the desired length of the curve is unknown. The grading increment must be adjusted several times until the desired curve length is achieved.
For this experiment, all three spec-sheets (A, B and C) are selected and graded as specified, and the L size is chosen as a base size. Curve measurements are shown in Table 3.
From Table 3, it can be deduced that if horizontal and vertical measurements are given, curves automatically intersect with each other. If, however, diagonal measurements are given for instance like armhole straight, the pattern grader then has to calibrate the measurements until front and back armhole curve lengths match with the front and back sleeve curve lengths.
The measurements should be checked and the grading increment should be adjusted until the required curve lengths are achieved.

Table 3: Comparison of curve lengths after conventional grading of different spec

Combination of POMs	POMs direction	Reference spec.	Measurement	Size					Unit
				S	M	L*	XL	XXL	
If SL, SO, AHS & US are given	Vertical, Horizontal, Diagonal & Diagonal	A	Front armhole curve	25.34	26.40	27.45	28.50	29.56	cm
			Front sleeve curve	25.84	26.64	27.45	28.25	29.06	
			Difference	+0.50	+0.24	0.00	-0.25	-0.50	
			Back armhole curve	25.25	26.30	27.35	28.40	29.45	
			Back sleeve curve	25.75	26.55	27.35	28.15	28.95	
			Difference	+0.50	+0.25	0.00	-0.25	-0.50	
If SL, SO, AHS & SW are given	Vertical, Horizontal, Diagonal& Horizontal	B	Front armhole curve	25.39	26.44	27.50	28.56	29.61	
			Front sleeve curve	25.90	26.70	27.50	28.30	29.10	
			Difference	+0.51	+0.26	0.00	-0.26	-0.51	
			Back armhole curve	25.34	26.40	27.45	28.50	29.56	
			Back sleeve curve	25.85	26.65	27.45	28.25	29.05	
			Difference	+0.51	+0.25	0.00	-0.25	-0.51	
If SL, SO, SCH& SW are given	Vertical, Horizontal, Vertical & Horizontal	C	Front armhole curve	25.39	26.45	27.50	28.55	29.61	
			Front sleeve curve	25.40	26.45	27.50	28.56	29.63	
			Difference	+0.01	0.00	0.00	+0.01	+0.02	
			Back armhole curve	25.35	26.40	27.45	28.50	29.56	
			Back sleeve curve	25.36	26.40	27.45	28.51	29.58	
			Difference	+0.01	0.00	0.00	+0.01	+0.02	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit (Explain tolerance limits) Tolerance = ± 0.20 cm, Units = Measured in cm*

2.2.3 Selection of base size in grading

If we choose jumping sizes rather than moving gradually from one size to another, some measurements often exceed the tolerance limit.

The selection of the base size also has an influence over the pattern grading accuracy. Basically, there are three methods of recording the growth of the pattern:

- **Method 1:** Progressive increment of the base size (from smallest to the largest size).
- **Method 2:** Progressive increment or decrement of the base size to acquire all the sizes from the smallest to the largest.
- **Method 3:** Digressive decrement of the base size to the smallest size.

After evaluating the graded measurement from Table 4, it can be deduced that horizontal and vertical measurements do not change even if the base size changes. The reasoning behind is that they were plotted along X and Y axis of Cartesian coordinates. However, inclined measurements of a graded pattern are inconsistent and sometimes exceed the tolerance limit if the base size changes. Additionally, greater variations are found from the smallest and to the largest base size. So, if the middle size from the provided size chart is considered as a base size (e.g. L as base size, if the size chart contains S, M, L, XL and XXL size), the errors can be minimised as they can have both positive and negative direction towards the given tolerance. So, the deficiencies of inclined measurements grading can be minimized by selecting the middle size as the base size.

Another reason for the selection of the base size is the presence of breakpoint. The breakpoint of a size chart is such a measurement upon whose increment, graded pattern varies. For instance, if mentioned half-chest is 46, 48, 50, 52, 55, and 58 (units in cm) respectively for six sizes; the base size should be the size which contains half-chest 52 (units in cm), so that both sides' measurement differences would be the same. It is recommended to grade from middle size to all sizes to reduce measurement errors if diagonal measurements are given.

2.2.4 Presence of higher number of sizes

Diagonal measurements relating to grading error increase as the number of sizes in the spec sheet increases. If the grading is done to get the extreme sizes, then the design, drape and fit of the garment

Table 4: Length Comparisons of diagonal measurements of T-shirt Spec A

POMs	Size	Measurement comparison							
		Length required	Tol (±)	S→XXL		S←L→XXL		XXL→S	
				Got	Error	Got	Error	Got	Error
Shoulder	S	15	0.15	15.00*	0.00	15.10	+0.1	15.18	+0.18
	M	16		15.95	-0.05	16.05	+0.05	16.13	+0.13
	L	17		16.90	-0.10	17.00*	0.00	17.08	+0.08
	XL	18		17.86	-0.14	17.96	-0.04	18.04	+0.04
	XXL	19		18.82	-0.18	18.92	-0.08	19.00*	0.00
Armhole straight	S	24	0.30	24.00*	0.00	24.00	0.00	24.01	+0.01
	M	25		25.00	0.00	25.00	0.00	25.01	+0.01
	L	26		25.99	-0.01	26.00*	0.00	26.00	0.00
	XL	27		26.99	-0.01	27.00	0.00	27.00	0.00
	XXL	28		27.99	-0.01	28.00	0.00	28.00*	0.00
Sleeve armhole straight	S	25	0.30	25.00*	0.00	25.42	+0.42	25.84	+0.84
	M	26		25.79	-0.21	26.21	+0.21	26.63	+0.63
	L	27		26.58	-0.42	27.00*	0.00	27.42	+0.42
	XL	28		27.37	-0.63	27.79	-0.21	28.21	+0.21
	XXL	29		28.16	-0.84	28.58	-0.42	29.00*	0.00
Under sleeve	S	14	0.25	14.00*	0.00	13.82	-0.18	13.63	-0.37
	M	14.5		14.60	+0.10	14.40	-0.10	14.20	-0.30
	L	15		15.21	+0.21	15.00*	0.00	14.78	-0.22
	XL	15.5		15.84	+0.34	15.62	+0.12	15.38	-0.12
	XXL	16		16.48	+0.48	16.25	+0.25	16.00*	0.00

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

changes as well [6, 21, 22]. Moore et al. (2001) [23] recommend that no more than five sizes (two larger, two smaller and one base size) should be graded from the base size together using a simplified grading system; otherwise the average size range would then require multiple base sizes. A pattern should not be graded more than two sizes from the base size, so that the visual appearance remains unaffected [21].

Table 5: Measurements of two spec sheets having two different size numbers

POMs	Reference spec A					Reference spec D							Unit
	S	M	L	XL	XXL	XS	S	M	L	XL	XXL	3XL	
BND	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	cm
FND	8.00	8.50	9.00	9.50	10.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	
NW	16.00	17.00	18.00	19.00	20.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	
S	15.00	16.00	17.00	18.00	19.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	
SD	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
AHS	24.00	25.00	26.00	27.00	28.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	
HC	48.00	51.00	54.00	57.00	60.00	45.00	48.00	51.00	54.00	57.00	60.00	63.00	
HPS	70.00	72.00	74.00	76.00	78.00	68.00	70.00	72.00	74.00	76.00	78.00	80.00	
SL	21.00	22.00	23.00	24.00	25.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	
SO	18.00	19.00	20.00	21.00	22.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	
US	14.00	14.50	15.00	15.50	16.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50	

Table 6: Length Comparisons of T-shirt Spec A and D (diagonal measurements)

Points of Measures	Spec	Measurement comparison	Size							Tol (±)
			XS	S	M	L	XL	XXL	3XL	
Shoulder length	A	Length required	-	15.00	16.00	17.00	18.00	19.00	-	0.15 cm
		Length acquired	-	15.10	16.05	17.00*	17.96	18.92	-	
		Error	-	+0.10	+0.05	0.00	-0.04	-0.08	-	
	D	Length required	14.00	15.00	16.00	17.00	18.00	19.00	20.00	
		Length acquired	14.16	15.10	16.05	17.00*	17.96	18.92	19.89	
		Error	+0.16	+0.10	+0.05	0.00	-0.04	-0.08	-0.11	
Armhole straight	A	Length required	-	24.00	25.00	26.00	27.00	28.00	-	0.30 cm
		Length acquired	-	24.01	25.01	26.00*	27.00	28.00	-	
		Error	-	+0.01	+0.01	0.00	0.00	0.00	-	
	D	Length required	23.00	24.00	25.00	26.00	27.00	28.00	29.00	
		Length acquired	23.01	24.01	25.01	26.00*	27.00	28.00	29.00	
		Error	+0.01	+0.01	+0.01	0.00	0.00	0.00	0.00	
Sleeve armhole straight	A	Length required	-	25.00	26.00	27.00	28.00	29.00	-	0.30 cm
		Length acquired	-	25.43	26.21	27.00*	27.79	28.57	-	
		Error	-	+0.43	+0.21	0.00	-0.21	-0.43	-	
	D	Length required	24.00	25.00	26.00	27.00	28.00	29.00	30.00	
		Length acquired	24.63	25.43	26.21	27.00*	27.79	28.57	29.37	
		Error	+0.63	+0.43	+0.21	0.00	-0.21	-0.43	-0.63	
Under sleeve	A	Length required	-	14.00	14.50	15.00	15.50	16.00	-	0.25 cm
		Length acquired	-	13.82	14.40	15.00*	15.62	16.25	-	
		Error	-	-0.18	-0.10	0.00	+0.12	+0.25	-	
	D	Length required	13.50	14.00	14.50	15.00	15.50	16.00	16.50	
		Length acquired	13.26	13.82	14.40	15.00*	15.62	16.25	16.89	
		Error	-0.24	-0.18	-0.10	0.00	+0.12	+0.25	+0.39	

Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in ‘cm’.

Experts affirm that the base size should be graded no more than two sizes before another fit model is implemented and the closer the individual to the fit model standard, the fewer alterations are required. Taylor and Shoben (1990) [24] argues against the 2D system of grading and they state "fitting and balance faults will automatically occur to the graded garment range" and they also indicate that "the 2D system can be safely used for very-loose-fitting garments over a very limited size range (three sizes)".

For this experiment, two spec sheets having two different size numbers were selected (Table 5).

After comparing Table 2 with Table 6, it can be deduced that as the number of size increases, grading error increases as well. If the spec sheet contains 5 different sizes, the middle size should be selected [20]. But if the sizes are more than 7, then additional errors will be generated. Based on the previous studies this statement is well verified, Bye and DeLong (1994) [21] demonstrate that garment appearance and proportion are also affected when the pattern is graded more than two sizes from the base size while using standard grading practices. Moore et al. (2001) [23] recommend that no more than five sizes (two larger and two smaller) are to be graded together. The average size range would then require more than one base size. They gave examples of simplified systems that include grading information for nine sizes (three smaller and five larger than the base size), which is a common practice in the apparel industry. In accordance with the aforementioned studies, some CAD personnel in the industry generally perform the following things for minimizing grading errors instead of rectifying them. Even if number of sizes exceed 7 sizes or more, the total sizes are divided into two parts (e.g. a spec containing 10 different sizes). They thus separate them into two groups of 5 sizes each and then draw two patterns as the base size and finally grade them. However, if the size exceeds 15 sizes or more, the total sizes are divided into three groups, of which three base sizes are selected. Afterwards from the selected base size, three patterns are drawn and are then graded. It should also be noted that if it is possible to eliminate all the diagonal measurements from the spec sheet then the number of sizes in a size range does not influence the grading. Few companies within the industry fit more than one sample size, which is a common practice in the industry if garment sizes are more than five, like size 06 to size 18 with an increment of 2.

2.2.5 Combination of measurement points

Some lines can be drawn using different measurement combinations. For example, the shoulder line can be drawn using any two of the three

Table 7: Shoulder length comparison of different POMs combination

Combination of POMs	POMs direction	Reference spec.	Size→	S	M	L	XL	XXL	Tol (±)
If SD & S are given	Vertical & Diagonal	A	Required	15.00	16.00	17.00	18.00	19.00	0.15 cm
			Acquired	15.10	16.05	17.00*	17.96	18.92	
			Error	+0.10	+0.05	0.00	-0.04	-0.08	
If AS & S are given	Horizontal & Diagonal	B	Required	15.00	16.00	17.00	18.00	19.00	
			Acquired	15.07	16.03	17.00*	17.97	18.95	
			Error	+0.07	+0.03	0.00	-0.03	-0.05	
If AS & SD are given	Horizontal & Vertical	C	Required	15.34	16.29	17.24	18.20	19.16	
			Acquired	15.34	16.29	17.24	18.20	19.16	
			Error	0.00	0.00	0.00	0.00	0.00	
N.B. The value of column B is not given for Spec C because, according to that spec sheet, we need AS and SD to be correct. They thus must be compared them to get the shoulder.									
If AS & SD are given	Horizontal	C	Required AS	45.00	48.00	51.00	54.00	57.00	0.25 cm
			Acquired AS	45.00	48.00	51.00	54.00	57.00	
			Error	0.00	0.00	0.00	0.00	0.00	
	Vertical	C	Required SD	5.00	5.00	5.00	5.00	5.00	-
			Acquired SD	5.00	5.00	5.00	5.00	5.00	
			Error	0.00	0.00	0.00	0.00	0.00	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

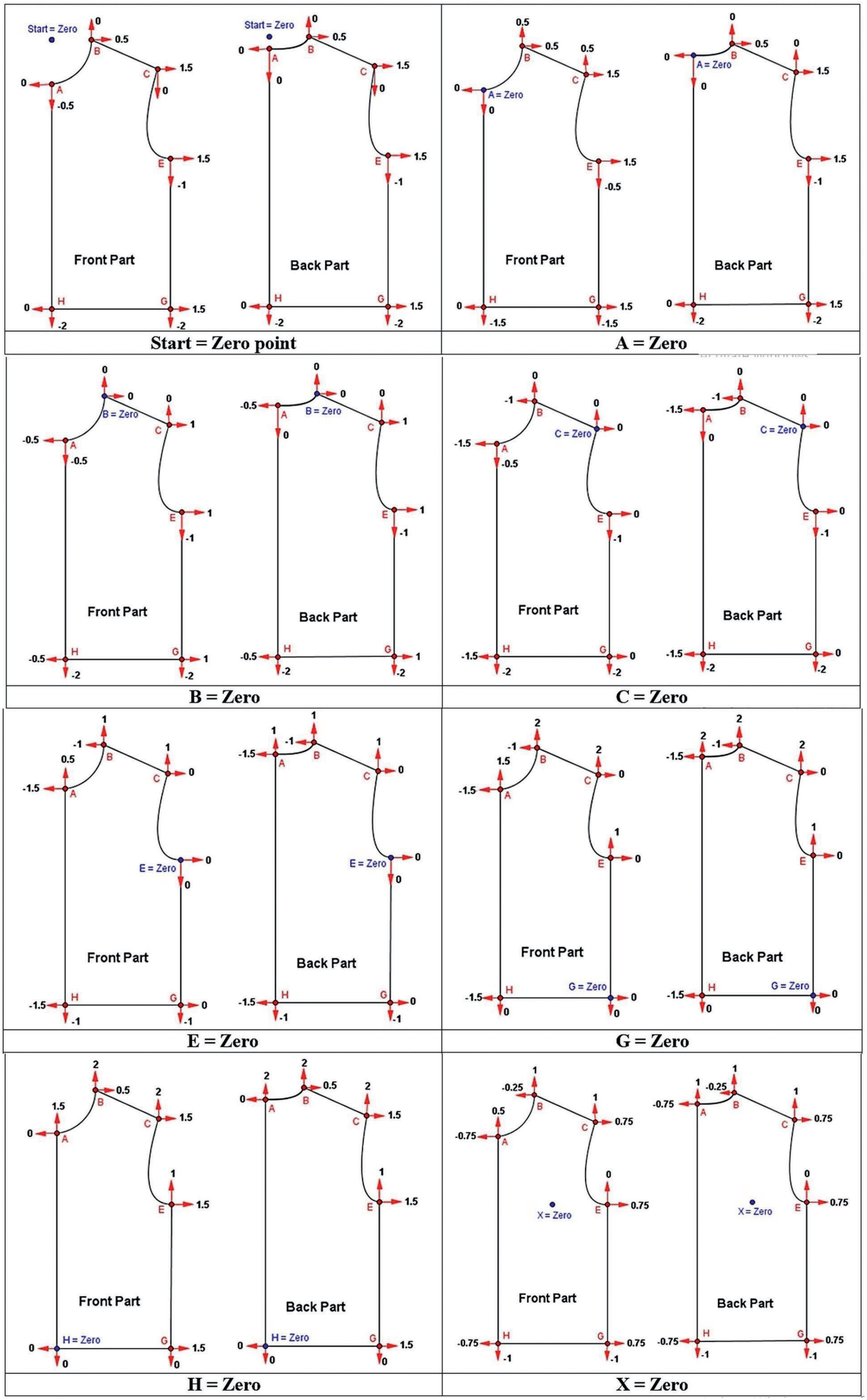


Figure 3: Grading increment of T-shirt Spec A (body part) by changing zero point

measurements, "Shoulder Length, Shoulder Drop and Across Shoulder Width".

It must be noted that some cardinal points of the pattern (e.g. shoulder point) can be created by using different measurement combinations. For instance, a shoulder point can be created if spec sheet contains horizontal-inclined (e.g. AS and S) or vertical-inclined (e.g. SD and S) or the horizontal-vertical (e.g. AS and SD) measurement combination. However, among the three options, the horizontal-vertical combination is preferable during pattern making as the measurement changes during grading are plotted in the Cartesian coordinates. For this experiment, three spec sheets A, B and C were chosen and were graded from base size L (middle size).

Table 7 clearly shows that shoulder point grading increment can be calculated without any error if horizontal and vertical POM combination is used, which can be plotted in X and Y direction respectively. The inclined graded measurement errors would not generally exceed the tolerance limit when any cardinal point of a pattern (e.g. shoulder point) is created from a horizontal-inclined (e.g. AS and S) or vertical-inclined (e.g. SD and S) measurement combination. However, better accuracy is found in the case of a horizontal-vertical combination.

Horizontal and vertical POMs should be used instead of diagonal or inclined POMs to get the desired shape of the pattern. During spec sheet creation, spec sheet creators should thus use the horizontal and vertical measurements instead of inclined measurements wherever it is possible.

2.2.6 Selection of zero points

The selection of a zero point is required to calculate accurate grading increment value within a minimum amount of time.

At first, a zero point has to be selected to apply grade rules or grading increment values. Then the values are calculated for a different grade or cardinal points. Each pattern grading starts by identifying the grainline, the zero point of reference, and the points where increases (or decreases for smaller sizes) are to be applied. It is necessary for any grading method to establish a point of reference for each pattern piece known as the zero point [25]. Moore et al. (2001) [23] used the centre front (and back) at the waist as the point of reference throughout their book. Vong, A. L. (2011) [4] states that "the location of the zero point on the pattern may change the grade of the pattern; additional study of whether the drape of the garment changes when the zero point is moved is needed". To check the impact of zero-point selection in grading, an experiment was conducted from spec sheet B by changing the zero point as mentioned in Table 6, as well as in Figure 3.

Based on the experiment it is evident that the graded patterns consistently have the same measurements. It can therefore be concluded that the change in zero-point location does not impact the fitting unless the pattern is wrongly drafted. Consequently, the procedure was applied on the sleeve and the result remained the same. The presence of diagonal measurement produced some miscalculations, however, not due to the zero-point selection. If all the diagonal measurements are avoided, like for example in "spec C", the errors can be avoided as well.

Any cardinal point can be selected as zero point. However, the calculation becomes much easier if the starting point is selected as zero-point.

2.2.7 Angle of measurement

Criterion 1 of the book Sizing in Clothing written by Ashdown [25] states that "the measurement must be either horizontal or vertical". But even if the measurements are neither horizontal nor vertical, Pythagoras' law can be used for calculating grading increment properly. The angle is not a mandatory factor.

In the same book it is also stated that "the measurement must be either horizontal or vertical -shifting and edge-changes grading techniques use grading information that is either horizontal or vertical; angled measurements could be used for proportional grading or could be divided into horizontal and vertical components, but only if the angle is known." However, even if the angle is not given it can be calculated from the horizontal and the vertical component of measurement. Knowing the angle is not mandatory; an example is shown in Figure 4.

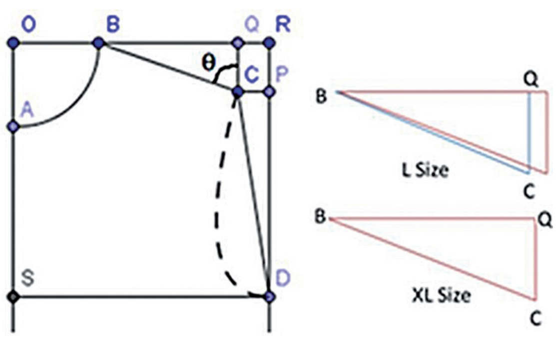


Figure 4: Body pattern of T-shirt (Spec A)

Angle can be measured by using the following formula:

$$\cos\theta = \frac{Shoulder\ drop}{Shoulder\ length} \quad (1)$$

$$\therefore \theta = cos^{-1}\frac{Shoulder\ drop}{Shoulder\ length} \quad (2)$$

After calculation the following data were found, Table 8.
In this way, it is not only possible to calculate the angle but also to reduce the grading errors. It must be noted that grading should be done manually or by using CAD software, which has an actual angle grading increment (e.g. Boke CAD) rather than employing an alternative reference line used by other software, such as Optitex, TUKA CAD, etc., which is elaborated more in section 2.2.9.
If diagonal measurements, such as shoulder length or armhole straight are given, then grading anomalies can be found. So, if diagonal measurements are given along with other horizontal or vertical components, then it is possible to calculate the angle and grade them to acquire more accurate graded measurements.

2.2.8 Alternative reference line

Some software uses an 'alternative reference line' for grading diagonal lines, but if the angle is not constant, they cannot grade the pattern accurately.
Generally, the reference line for grading is parallel to the grainline but sometimes an alternative reference line not parallel to the grainline is used. Taylor and Shoben (1984), Cooklin (1990), and Mullet et al., (2009) [6, 18, 26] use alternative reference lines for different garments when simple x and y orientation can distort the pattern shape. Generally, the alternative reference line is used for the shoulder/armscye point when the dart is rotated from the shoulder position [24, 27]. Mullet et al. (2009) [6] recommend alternative grade reference lines when "a style line on the pattern piece forms an acute angle to the grade reference line (x-axis) or when grading a curve that would be distorted by using the original axis".
From the above discussion, it can be deduced that the alternative reference line is only used for diagonal line grading. It is only applicable in case of most of the CAD software when the shoulders have the same angle, e.g. 17 degrees for all sizes. But if the shoulder angle varies from 17 degrees for L size to 18 degrees for XL size then most of the CAD cannot do that by

Table 8: Angle of shoulder slope of T-shirt body pattern (Spec A)

POMs	Remarks	Size					Unit
		S	M	L	XL	XXL	
Shoulder length?	Given in Spec A	15.00	16.00	17.00	18.00	19.00	cm
Shoulder drop		5.00	5.00	5.00	5.00	5.00	
Angle of BCQ (Figure 4)	Calculated values	70.53	71.79	72.90	73.87	74.74	Degree
Angle increment		-1.26	-1.11	Base	-0.97	-0.87	

Note: It is possible to calculate the angle of QBC also. But instead of QBC, BCQ is calculated because of angle grading by Boke CAD uses this angle, which is described in "2.2.9 Angle grading variation section"

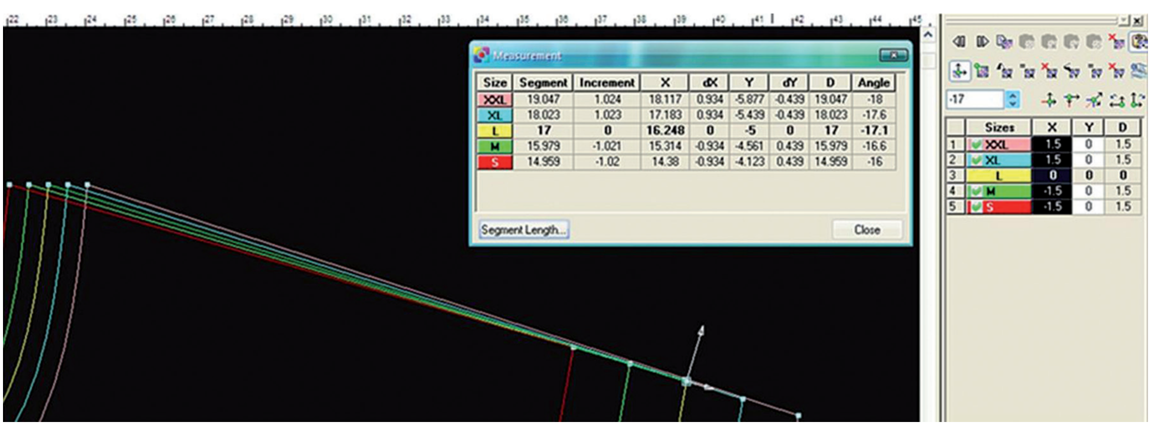


Figure 5: Shoulder grading of T-shirt Spec A by alternative reference line in TUKA CAD

Table 9: Comparison of measurement between XY grading and alternative reference line grading of Tshirt Spec A (TUKA CAD)

Points of measures (POMs)	Measurement comparison	Size					Tol (±)
		S	M	L	XL	XXL	
Shoulder length	Error with XY increment	+0.07	+0.03	0.00	-0.03	-0.05	0.20 cm
	Length with XY increment	15.07	16.03	17.00	17.97	18.95	
	Length required	15.00	16.00	17.00*	18.00	19.00	
	Length with alternative reference line	14.96	15.98	17.00	18.02	19.05	
	Error with alternative reference line	-0.04	-0.02	0.00	+0.02	+0.05	
Shoulder drop	Error with XY increment	0.00	0.00	0.00	0.00	0.00	0.00 cm
	Length with XY increment	5.00	5.00	5.00	5.00	5.00	
	Length required	5.00	5.00	5.00*	5.00	5.00	
	Length with alternative reference line	4.12	4.56	5.00	5.44	5.88	
	Error with alternative reference line	-0.88	-0.44	0.00	+0.44	+0.88	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

alternative reference line, which is actually known as "Angle grading" as it will distort the across shoulder or shoulder drop measurement.

It is evident from the findings of Table 9 that alternative reference line grading cannot solve the grading problem.

If the angle is constant, then the usage of Optitex or TUKA CAD's alternative reference line grading is recommended.

2.2.9 Angle grading variation

Sometimes shoulder slope angle is not constant throughout all the sizes, so it results in grading error if alternative reference line grading is used.

Alternative reference line is actually known as 'angle grading' in apparel CAD software. Angle grading varies in different software such as TUKA CAD, Optitex etc. CAD system uses an alternative reference line in angle grading, whereas Boke CAD uses actual angle increment in angle grading. Examples are shown in Figure 6.

From the Table 10, it is clear that the actual angle grading can solve the grading problem.

If the angle remains inconstant then the use of Boke CAD's angle grading, instead of alternative reference line grading by Optitex, TUKA CAD software, etc is advised.

2.2.10 Selection of grade point or absence of certain measurements

Different shaping errors (e.g. armhole shape curve) occur due to the absence of some measurement points.

Grade point or cardinal points are those points that are present at the perimeter of the pattern and distribute the changes in body dimension [4]. Grade points are also known as cardinal points [6]. Solinger, (1988) [28] states that "when grading, the 'essence' of a garment should be maintained through all sizes". Doyle and Rodgers (2003) [17] state the importance of keeping the curves of the base pattern consistent: "If the grader changes the shape of the curve, the fit of the garment changes". Taylor and Shoben (2004) [18] state that while grading the armhole shape, "the angles at the cardinal point on the pattern must remain the same on all sizes". After grading, seam lines of the

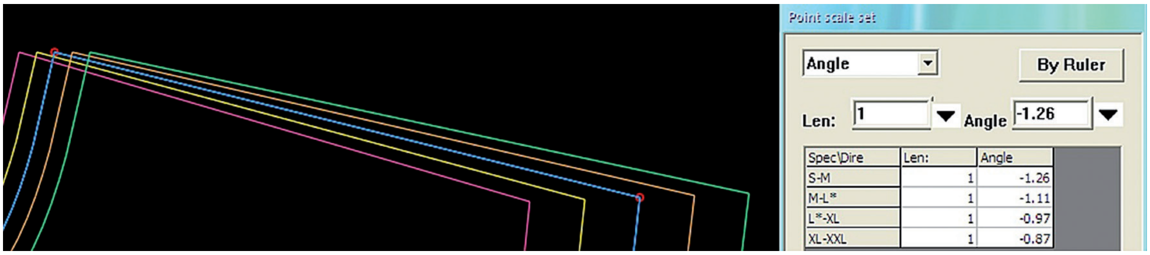


Figure 6: Shoulder grading of T-shirt spec A by actual angle grading in Boke CAD

Table 10: Comparison of measurement between XY grading and angle grading of T-shirt spec A by Boke CAD (shoulder length and shoulder drop)

Points of Measures (POMs)	Measurement comparison	Size					Unit
		S	M	L	XL	XXL	
Shoulder Length	Error with XY increment	+0.10	+0.05	0.00	-0.04	-0.08	cm
	Length with XY increment	15.10	16.05	17.00	19.96	18.92	
	Length Required	15.00	16.00	17.00*	18.00	19.00	
	Length with angle grading	15.00	16.00	17.00	18.00	19.00	
	Error with angle grading	0.00	0.00	0.00	0.00	0.00	
Shoulder drop	Error with XY increment	0.00	0.00	0.00	0.00	0.00	
	Length with XY increment	5.00	5.00	5.00	5.00	5.00	
	Length Required	5.00	5.00	5.00*	5.00	5.00	
	Length with actual angle	5.00	5.00	5.00	5.00	5.00	
	Error with actual angle	0.00	0.00	0.00	0.00	0.00	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

graded pattern should be checked to ensure that they are of the same length during sewing.

Some spec sheets provide measurements for across chest and back. Occasionally, such measurements are absent in some spec sheets. In that case, pattern makers construct front and back armhole curve lines from shoulder point to underarm point. Sometimes the shape of armhole curves might be imperfect due to the absence of armhole curve depth, i.e. absence of across chest and across back measurements. And if these measurements are not given, the grading increment values for middle point of the curves (e.g. across chest and across back point) remain unknown. Different examples of armhole curve shapes are shown in Figure 7, indicated by red, green and blue colour.

If the across chest and across back measurements are provided in the spec sheet, the curves become more precise. When the curves are drawn from the shoulder point, across chest or across back and underarm point to avoid the fitting problem the curves do not require readjustment for adjacent sizes as then grading increment values can be calculated.

In short, across chest and across back measurements are to be used for drawing armhole shape curves accurately. Most of the time, pattern shape related problems occur due to the absence of curve depth. So, if AC and AB are given, then armhole shape curves can be drawn through three points: shoulder point, across chest/across back point and armpit point.

Across chest and across back measurements should be used for drawing armhole shape curves. For better armhole shape, the following things can be done:

- Manual drawing by French curve [29]
- Saving and selection of curve (e.g. Gemini CAD French curve tool)

2.2.11 Absence of measurement location

If some measurements are absent in the spec sheet (e.g. across chest and across back position) or even

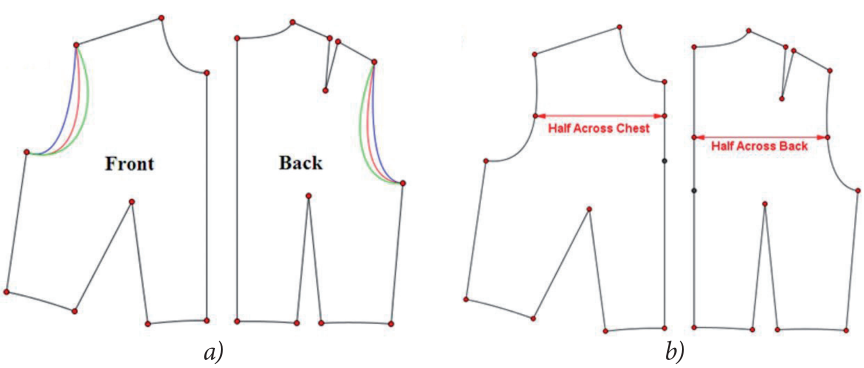
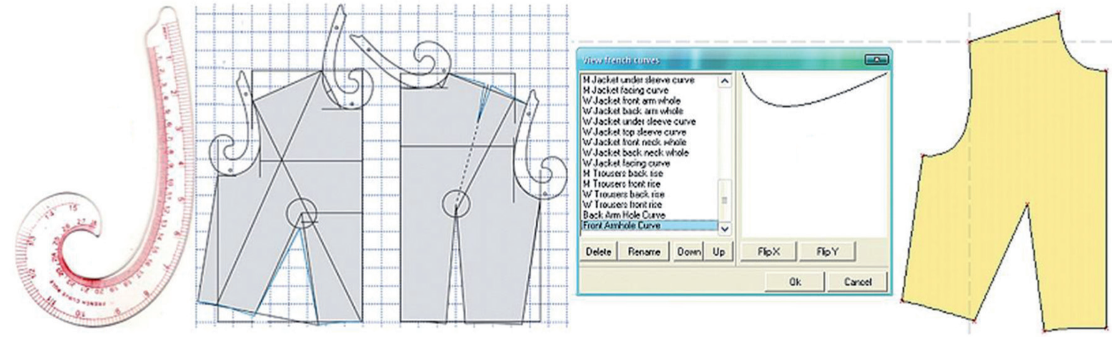


Figure 7: a) Tentative armhole curve from shoulder point to armpit point without across chest and across back; b) accurate armhole curve from shoulder point to armpit point with across chest and across back measurements



a) b)

Figure 8: a) French curve and their uses for manual armhole curve drawing; b) saving and selection of curve by Gemini CAD French curve tool

in the standard measurement chart, the shape of the pattern changes and fitting problems occur.

Some spec sheets have across chest and back but do not have their vertical position from HPS. Sometimes, they are not properly clarified in standard measurement charts. Different pattern making books provide different guidelines on how to make the vertical position of across chest and back measurements. Different armhole curves were therefore drawn indicating different colours in Figure 9 according to the different procedures, which are mentioned below.

In the developed method, across chest position from armpit point (X–Y, in Figure 10) is one-third of armscye depth (W–X, in Figure 10) and across back position from armpit point (XX–YY, in Figure 10) is one-third of armscye depth (WW–XX, in Figure 10). It can be concluded from Figure 9 and Figure 10 that green and red colour give more accurate shapes.

For better armhole curve shape, the across chest and across back position should be drawn by dividing the armscye depth into two-third of its original length from the neck point, if across chest and across back position are absent.

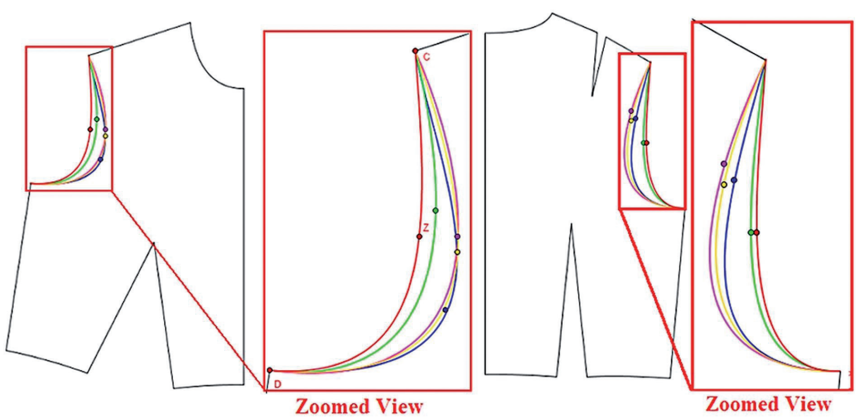


Figure 9: Front bodice and back bodice with five different armhole curve shapes constructed with different procedures

Table 11: Colour code of armhole curve, including developed method for across chest and back position

Colour code	Method
Red	developed method
Blue	Helen Joseph Armstrong (2010)[30]
Green	Winifred Aldrich (2008) [31]
Pink	Bina Abling and Kathleen Maggio (2008) [32]
Gold	http://fashionauntie.blogspot.com/2012/02/first-stages-of-pattern-drafting-for.html [33]

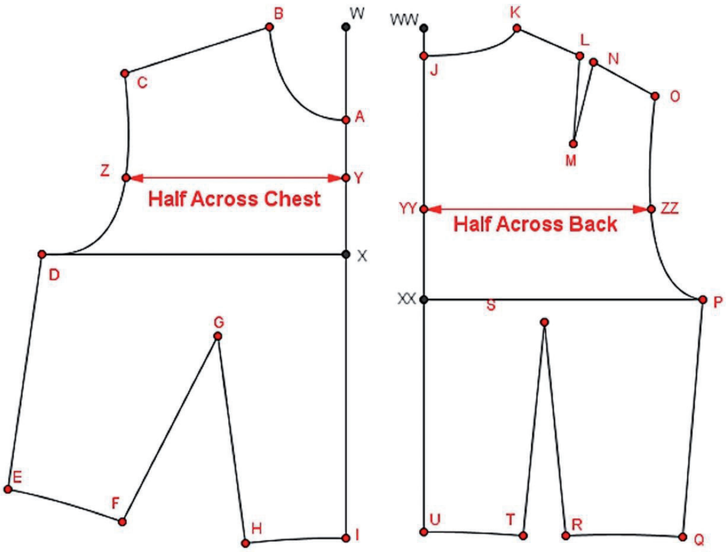


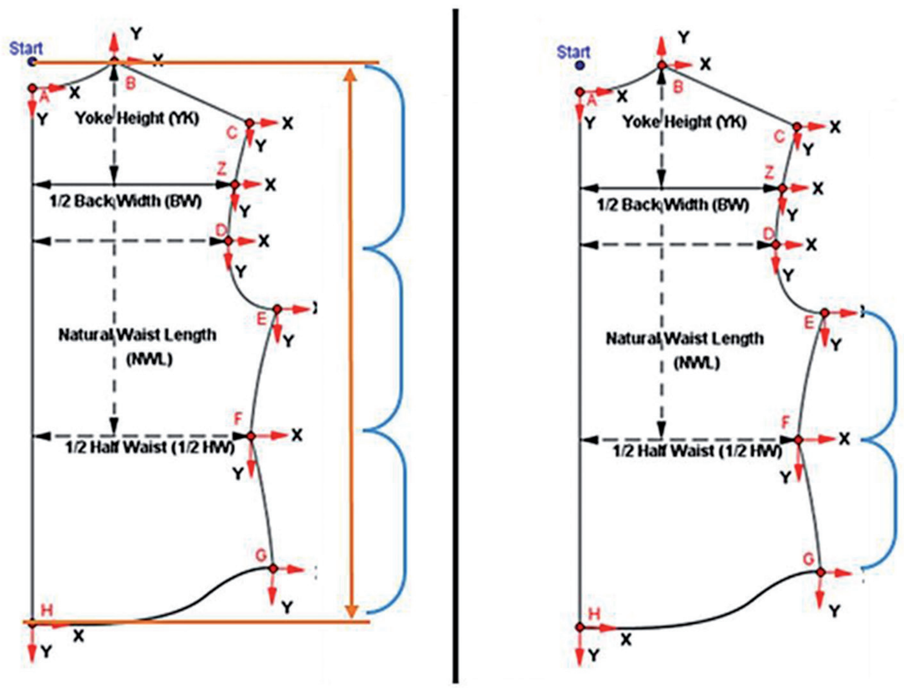
Figure 10: Front and back part of bodice block [developed method]

2.2.12 Lack of proper drafting procedure

Inadequate drafting procedure can sometimes lead to grading errors as the grading relates to the pattern making procedure.

Sometimes buyers gave us a soft copy of a pattern along with the spec sheet. Then the pattern maker graded the pattern. So, if the drafting procedure is unknown to the grader, grading errors are plausible.

On some other occasions, buyers gave us a soft copy of pattern along with the spec sheet but without any natural waist length (NWL) measurement (Figure 11). Different pattern makers use different techniques to meet the standard length of given measurements in the spec sheet, if it is absent in the spec sheet. For instance, some pattern makers use "2/3 of the total body length from high point of shoulder to ½ waist



A) B)

Figure 11: Different drafting procedure of NWL

position" for calculating NWL if it is not provided in the spec sheet. According to the 8 head theory, the NWL position is the second head position from the neckline, and hip position is the third head position (Figure 11A). Other pattern makers use half of the side seam measurements (Figure 11B). So, if any measurement or procedure is unknown to the grader it then becomes very difficult to grade the pattern with accurate measurement.

It can be concluded from Figure 11 that if the procedure is unknown to the grader it leads to grading errors as grading increment value depends on the pattern drafting procedure. When manufacturers only need to grade the pattern, the grader should be familiar with the procedure unless the grading increment values are provided in the Tech Pack.

2.2.13 Non-identifiable body landmarks or unusual measurement

Some measurements used in the spec sheet do not relate to the identifiable body landmarks. Furthermore, measurements are sometimes unknown to the majority of pattern makers.

Different pattern makers use different methods along with different measurements for the same design. But some measurements used in the body measurement chart are not related to the identifiable body landmarks. For example, a world-famous pattern maker Helen Joseph Armstrong (2010) [30] uses 'new strap measurement' (Figure 12), which is neither used by any pattern maker nor present in any body-measurement chart.

Though Helen Joseph Armstrong's (2010) [30] method gives the best fitting due to unconventional measurement, it would be difficult to grade the pattern. As seen in Figure 12, the measurement is neither perfectly diagonal nor a curve measurement, which can be measured through some definite points. In pattern making such measurements should be used that do not impact the grading and unusual measurements should therefore be avoided if they cause grading deficiencies.

2.2.14 Manual vs. computerised method of grading

Manual grading is a time-consuming and troublesome process whereas computerised grading is much more convenient and precise.

Often, the accuracy of the graded pattern pieces of clothing is affected by grader's skill [34]. The manual procedure of grading is exceptionally tedious and grading efficiency is affected by grader's experience [14]. Although the 2D CAD system provides time-saving solutions, they are not free from limitations. The grade rule creation or grading increment calculation is used by all types of 2D CAD system for apparel. But to complete the grading process, manual calculation and inputs are required for 2D CAD [14]. Computerised pattern grading is the most precise and expedient method but only when the accurate values are entered into the computer [6].

It is evident that manual grading is less efficient than the computerised method and usage of computerised grading is therefore recommended if possible.

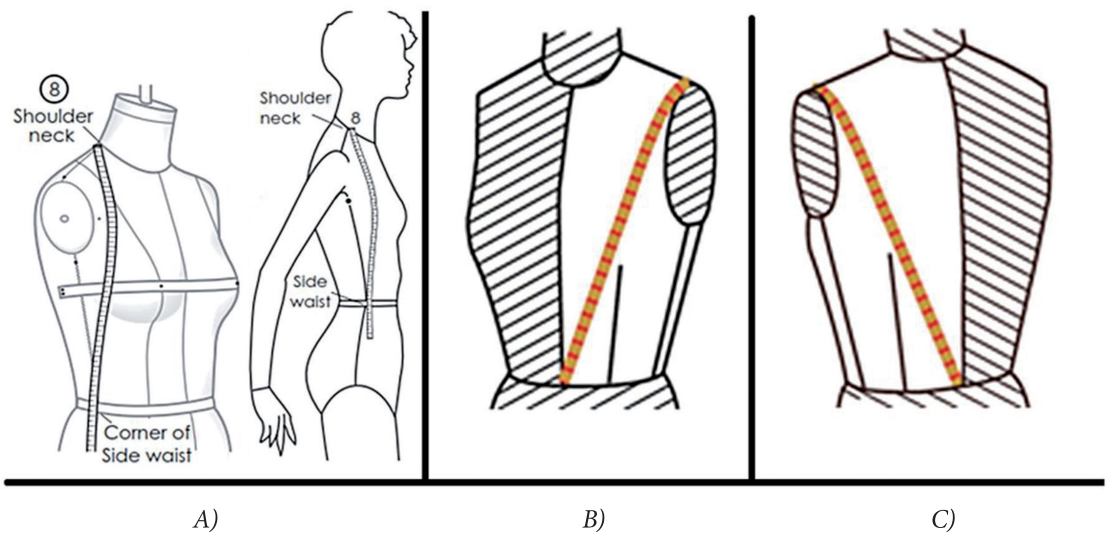


Figure 12: List of some non-identifiable body measurements. A – new strap, B – front shoulder slope, C – back shoulder slope

3 Results and discussion

After conducting all grading experiments, different problems are identified and finally, some recommendations are given for every problem. Different kinds of spec sheets were provided by different buyers with different POM variations. So, it is necessary to learn the proper grading calculation method and how the patterns are actually made from different measurements. Grade rule calculation has to be done in such a way that minimum measurement errors occur from graded pattern pieces and also, styles features left intact. The recommendations are given so that pattern graders can use them as a reference or guideline to avoid unnecessary grading problems.

3.1 General recommendations

i. **Presence of diagonal measurements.** The diagonal measurements should be avoided as much as possible in the spec sheet because they cause grading deficiency.

ii. **Maintaining accuracy and matching of curve lines.** Measurement checking and optimisation of the grading increment should be done until the required curve lengths are achieved.

iii. **Selection of base size.** If diagonal measurements are provided, then grading should be done from middle size to all sizes in order to reduce measurements errors.

iv. **Presence of higher number of sizes.** If the spec sheet contains 5 to 7 sizes, the middle size should be selected. If the number of sizes exceeds 7 or more, then the total number of sizes should be divided into two parts, and two base sizes should be selected. Afterwards, grading should be done by drawing two separate patterns. Even if the number of total sizes exceeds 15 or more, the total sizes should be divided into three individual parts. And then by selecting three base sizes, three individual patterns are to be drawn and later graded. It should also be noted that if it is possible to eliminate all the diagonal measurements from the spec sheet then the number of sizes in a size range does not influence the grading.

v. **Combination of measurements.** Horizontal and vertical POMs should be used instead of diagonal or inclined POMs to achieve the desired shape of pattern wherever possible. During the creation of spec sheets, spec sheet creators should use horizontal and vertical measurements instead of inclined measurements wherever possible.

vi. **Selection of zero points.** Any cardinal point can be selected as zero point but if the starting point is selected as zero-point, the calculation becomes easier. The starting point should therefore be chosen as zero point.

vii. **The angle of measurement.** If diagonal measurements, such as shoulder or armhole straight are given, then grading anomalies are found. If diagonal measurements are provided along with other horizontal or vertical components, then it is possible to calculate the angle and grade them to get more accurate graded measurements.

viii. **Alternative reference line.** If the angle is constant, then the usage of Optitex or TUKA CAD's alternative reference line grading is recommended.

ix. **Angle grading variation.** If the angle is not constant then the usage of Boke CAD's angle grading instead of alternative reference line grading by Optitex, TUKA CAD software etc. are advised.

x. **Selection of grade point or absence of certain measurements.** Across chest and across back measurements are to be used for drawing armhole shape curves. For better armhole shape, the following recommendations can be employed: A) Manual drawing by French curve, B) Saving and selection of curve (e.g. Gemini CAD French curve tool).

xi. **Absence of measurement location.** For better armhole curve shape, the across chest and across back position should be drawn by dividing the armscye depth into 2/3 from neck point if across chest and across back position are not given.

xii. **Lack of proper drafting procedure.** When manufacturers only need to grade the pattern, the procedure should be well-known to the grader unless the grading increment values are provided in the Tech Pack.

xiii. **Non-identifiable body landmarks or unusual measurement.** Unusual measurements should be avoided if they cause grading deficiencies.

xiv. **Manual vs. computerised method of grading.** It is evident that manual grading is less efficient than a computerised method, so it is recommended to use computerised grading if possible.

4 Conclusion

Pattern grading is the most popular method in ready-made garment industries for large scale manufacturing of different sizes, even though grading calculation can sometimes be complex. Grading is still popular because it is less time consuming and cost-efficient in making different sized patterns during production. However, defective grading affects other computerised downstream operations, such as computerised marker making and computerised cutting. It is important to note that although computer-aided applications contributed to minimising production costs and improving manufacturing efficiency, it cannot satisfy the customer's need for individualisation. Although grading calculation is very complex, patterns can be graded successfully without errors and distortion of style features, if the calculation is done properly. It will not only reduce the sample approval time, but will also help us to create clothing that fits better on the wearer's body.

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