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An Approach in Finding Number of Optimal Groups for Group Chain Acceptance Sampling Plans (GChSP) by using Minimum Angle Method

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Abstract: There are several methods used such as minimizing the consumer's risk and minimum angle method (minimizing consumer's and producer's risks simultaneously) when developing a new acceptance sampling plan. For the minimizing consumer's risk method, researchers have conducted a thorough research and all the findings using this method are well-discussed. However, for the minimum angle method, there is a slight issue when researchers discuss their findings which is they do not present the ultimate finding using the proposed method. That is the number of groups reported in the findings does not reflect the number of optimal groups associated with the smallest angle. Therefore, this study proposes an approach for finding number of optimal for Group Chain acceptance Sampling Plan (GChSP) by using minimum angle method. By using this approach, the number optimal of groups is obtained when the angle has the smallest value. The smallest angle is crucial, since, it discriminates a good lot and a bad lot better. Apart from that, it resembles the ideal Operating Characteristic (OC) curve.

Key words: Group chain acceptance sampling plan, number of optimal groups, minimum angle method, consumer's risk, producer's risk, slight issue

INTRODUCTION

Quality Control (QC) involves three different areas which are Statistical Process Control (SPC), Design of Experiment (DOE) and acceptance sampling. Stapenhurst (2005) defines SPC in his book as the use of tools and techniques based on statistical principal in order to manage and improve of the processes. For DOE, Montgomery (2009) states that it plays a crucial part in identifying the key variables influencing the characteristics of interest in the process. Meanwhile acceptance sampling is defined as a set of procedure where a sample is taken from a lot of products, the inspection activity is conducted and the final decision is either the products would be accepted or rejected (Montgomery, 2009). For this study, it only focuses on the third area which is acceptance sampling.

Since, acceptance sampling only inspects a random sample taken from the lot of products, therefore, there is possibility of making a wrong decision or known as risk. There are two risks associated with acceptance sampling which are consumer's risk, β and producer's risk, α. Consumer's risk, β is defined as probability of accepting a lot of products with poor quality meanwhile producer's risk, α denotes the probability of rejecting a lot of products with good quality (Montgomery, 2009; Schilling and Neubauer, 2017).

One basic development of acceptance sampling is it started with Single acceptance Sampling Plan (SSP) (Epstein, 1954), Chain acceptance Sampling Plan (ChSP) (Dodge, 1955) and Group Chain acceptance Sampling Plan (GChSP) (Mughal *et al*., 2015a, b). For each sampling plan, the development is triggered by different factors such the minimum sample size for SSP, higher quality products for ChSP and reducing cost and inspection time for GChSP.

At the early stage of sampling plans development, most researchers only focus on minimizing the consumer risk's, β. These include Gupta and Groll (1961), Rosaiah and Kantam (2005), Tsai and Wu (2006) and Aslam *et al*. (2010) for the SSP. For ChSP, Ramaswamy and Sutharani (2013), Ramaswamy and Jayasri (2014) extensively developed the plan for three different distributions. Apart from them, Mughal *et al*. (2015a, b) also produced the plan

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for Pareto distribution of the 2nd kind. For GChSP, five different distributions have been applied to it such as Pareto distribution of the 2nd kind, Rayleigh distribution, log-logistic distribution, inverse Rayleigh distribution and exponential distribution by Mughal *et al*. (2015a, b) and Teh *et al*. (2016a-c, 2018).

There is a method in the acceptance sampling where both risks will be considered and it is called minimum angle method. The method has been applied to several sampling plans such as Double acceptance Sampling Plan (DSP) and Bayesian double acceptance Sampling Plan (BChSP-1) (Ramaswamy and Sutharani, 2013; Suresh and Usha, 2016). It has been shown that the minimum angle method produced optimum number of sample size and probability of lot acceptance (Ramaswamy and Sutharani, 2013).

However, there is a small issue when developing any sampling plan using minimum angle method. Previous researchers do not really show the number of optimal groups when presenting their findings. In fact, they only showed the number of groups which actually does not have smallest angle. Therefore, this study proposes an approach for finding the number of optimal groups associated with the smallest angle created using the minimum angle method.

MATERIALS AND METHODS

Minimum angle method: The minimum angle method considers the tangent angle between the lines joining the points Acceptable Quality Level (AQL, 1-α) and Limiting Quality Level (LQL, β) as shown in Fig. 1 where p_1 = AQL and p_2 = LQL. AQL represents the worst quality level that the customer would consider to accept the product as the average process and LQL is poorest level that the customer is willing to accept a product as individual (Montgomery, 2009). In acceptance sampling, α_1 is usually associated with producer's risk and on the other hand, β_2 is related to the consumer's risk. By using this method, an experimenter can obtain better discriminating plan in accepting good lots. Tangent of the angle made by the line CA and AB is given by:

$$\tan\theta = \frac{BC}{AC} = \frac{(p_2 - p_1)}{L(p_1) - L(p_2)}$$

When the value of $\tan\theta$ is smaller, then the angle would be smaller too. This condition makes the AB chord approaches the AC chord which is actually the ideal Operating Characteristic (OC) curve in

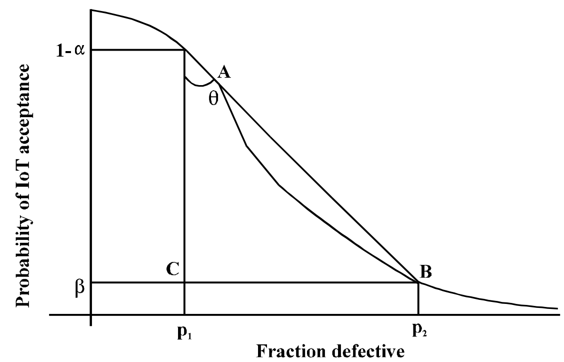

Fig. 1: Minimum angle method. Adapted from designing double acceptance sampling plans based on truncated life tests in Rayleigh distribution using minimum angle method by Ramaswamy and Sutharani (2013)

acceptance sampling. This method minimizes both risks simultaneously which both parties will favour this sampling plan.

Design of GChSP: The operating steps for GChSP are as follows in algorithm 1:

Algorithm 1; GChSP:

Step 1: Find the number of groups, g

Step 2: Allocate number of product (r) to each group. The sample size n = g*r

Step 3: Count the number of failure (d) during test termination time (t_0)

Step 4: Accept the lot if d = 0
Accept the lot if d = 1, given that there is no failure recorded in the preceding i lots
Reject the lot if d>1

Generalized exponential distribution: For generalized exponential distribution, the Cumulative Distribution Function (CDF), the mean, μ and the test termination time, t_0 are used in deriving the probability of failure, p. The CDF of the distribution is given by:

$$F(t;\sigma) = \left[1 - \exp\left(-\frac{t}{\sigma}\right)\right]^{\lambda},\ t > 0,\ \lambda > 0$$

where σ and λ are the scale and shape parameters. The mean of distribution is:

$$\mu = \sigma$$

The test termination time, t_0 is defined as a product of specified constant, a specified mean life, μ_0 such that:

$$t_0 = a\mu_0$$

The probability of failure, p is obtained as:

$$p = \left[1-\exp\left[-\alpha\left(\frac{\mu_0}{\mu}\right)\right]\right]^{\lambda}$$

The probability of lot acceptance, L(p) for GChSP is given by:

$$L(p) = (1-p)^{gr} + grp(1-p)^{gr-1}(1-p)^{gri}$$

RESULTS AND DISCUSSION

For the proposed GChSP, the number of possible groups is obtained when it satisfies one condition which is both risks (producer's and consumer's) are <0.10. Table 1 shows the number of groups for the GChSP for generalized exponential distribution with the specified shape and design parameters are (λ, μ/μ_0, a, i, r) = (2, 8, 0.25, 1, 2).

Table 1: Number of groups for generalized exponential distribution with respective shape and design parameters

Shape and design parameters (λ, μ/μ_0, a, i, r) = (2, 8, 0.25, 1, 2)

g	α_1	β_2	$L(p_1)$	$L(p_2)$	(Theta)
1	0.0000045	0.9887211	0.9999955	0.9887211	76.7770925°
2	0.0000196	0.9559433	0.9999804	0.9559433	47.4551396°
3	0.0000454	0.9091454	0.9999546	0.9091454	27.8514397°
4	0.0000818	0.8538650	0.9999182	0.8538650	18.1867742°
5	0.0001286	0.7941513	0.9998714	0.7941513	13.1290398°
6	0.0001858	0.7329169	0.9998142	0.7329169	10.1917015°
7	0.0002533	0.6722122	0.9997467	0.6722122	8.3343205°
8	0.0003311	0.6134378	0.9996689	0.6134378	7.0817208°
9	0.0004191	0.5575085	0.9995809	0.5575085	6.1946292°
10	0.0005172	0.5049801	0.9994828	0.5049801	5.5421641°
11	0.0006253	0.4561457	0.9993747	0.4561457	5.0477396°
12	0.0007434	0.4111099	0.9992566	0.4111099	4.6640064°
13	0.0008714	0.3698448	0.9991286	0.3698448	4.3603309°
14	0.0010093	0.3322319	0.9989907	0.3322319	4.1161263°
15	0.0011569	0.2980936	0.9988431	0.2980936	3.9171062°
16	0.0013142	0.2672168	0.9986858	0.2672168	3.7530795°
17	0.0014811	0.2393691	0.9985189	0.2393691	3.6166018°
18	0.0016575	0.2143119	0.9983425	0.2143119	3.5021211°
19	0.0018435	0.1918079	0.9981565	0.1918079	3.4054212°
20	0.0020388	0.1716278	0.9979612	0.1716278	3.3232485°
21	0.0022436	0.1535534	0.9977564	0.1535534	3.2530565°
22	0.0024576	0.1373804	0.9975424	0.1373804	3.1928270°
23	0.0026808	0.1229192	0.9973192	0.1229192	3.1409425°
24	0.0029132	0.1099953	0.9970868	0.1099953	3.0960935°
25	0.0031546	0.0984495	0.9968454	0.0984495	3.0572103°
26	0.0034051	0.0881371	0.9965949	0.0881371	3.0234122°
27	0.0036645	0.0789271	0.9963355	0.0789271	2.9939687°
28	0.0039328	0.0707017	0.9960672	0.0707017	2.9682702°
29	0.0042100	0.0633548	0.9957900	0.0633548	2.9458046°
30	0.0044959	0.0567916	0.9955041	0.0567916	2.9261398°
31	0.0047905	0.0509269	0.9952095	0.0509269	2.9089092°
32	0.0050937	0.0456851	0.9949063	0.0456851	2.8938004°
33	0.0054056	0.0409983	0.9945944	0.0409983	2.8805464°
34	0.0057259	0.0368062	0.9942741	0.0368062	2.8689179°
35	0.0060546	0.0330553	0.9939454	0.0330553	2.8587173°
36	0.0063918	0.0296977	0.9936082	0.0296977	2.8497741°
37	0.0067372	0.0266908	0.9932628	0.0266908	2.8419404°
38	0.0070910	0.0239970	0.9929090	0.0239970	2.8350877°
39	0.0074529	0.0215825	0.9925471	0.0215825	2.8291042°
40	0.0078230	0.0194174	0.9921770	0.0194174	2.8238921°
41	0.0082011	0.0174751	0.9917989	0.0174751	2.8193662°
42	0.0085873	0.0157320	0.9914127	0.0157320	2.8154514°
43	0.0089814	0.0141670	0.9910186	0.0141670	2.8120821°
44	0.0093834	0.0127613	0.9906166	0.0127613	2.8092002°
45	0.0097933	0.0114981	0.9902067	0.0114981	2.8067550°
46	0.0102109	0.0103627	0.9897891	0.0103627	2.8047012°
47	0.0106362	0.0093416	0.9893638	0.0093416	2.8029990°
48	0.0110693	0.0084231	0.9889307	0.0084231	2.8016134°
49	0.0115099	0.0075965	0.9884901	0.0075965	2.8005128°
50	0.0119581	0.0068525	0.9880419	0.0068525	2.7996697°
51	0.0124137	0.0061825	0.9875863	0.0061825	2.7990593°

Table 1: Continue

Shape and design parameters (λ, μ/μ_0, a, i, r) = (2, 8, 0.25, 1, 2)

g	α_1	β_2	$L(p_1)$	$L(p_2)$	(Theta)
52	0.0128768	0.0055791	0.9871232	0.0055791	2.7986597°
53	0.0133473	0.0050353	0.9866527	0.0050353	2.7984512°
54	**0.0138251**	**0.0045453**	**0.9861749**	**0.0045453**	**2.7984165°**
55	0.0143102	0.0041036	0.9856898	0.0041036	2.7985400°
56	0.0148025	0.0037054	0.9851975	0.0037054	2.7988076°
57	0.0153019	0.0033462	0.9846981	0.0033462	2.7992070°
58	0.0158084	0.0030222	0.9841916	0.0030222	2.7997269°
59	0.0163220	0.0027299	0.9836780	0.0027299	2.8003574°
60	0.0168426	0.0024661	0.9831574	0.0024661	2.8010895°
61	0.0173701	0.0022280	0.9826299	0.0022280	2.8019151°
62	0.0179044	0.0020131	0.9820956	0.0020131	2.8028269°
63	0.0184457	0.0018191	0.9815543	0.0018191	2.8038186°
64	0.0189936	0.0016439	0.9810064	0.0016439	2.8048841°
65	0.0195484	0.0014857	0.9804516	0.0014857	2.8060183°
66	0.0201097	0.0013428	0.9798903	0.0013428	2.8072164°
67	0.0206777	0.0012137	0.9793223	0.0012137	2.8084741°
68	0.0212523	0.0010971	0.9787477	0.0010971	2.8097876°
69	0.0218334	0.0009918	0.9781666	0.0009918	2.8111533°
70	0.0224209	0.0008966	0.9775791	0.0008966	2.8125681°
71	0.0230149	0.0008106	0.9769851	0.0008106	2.8140292°
72	0.0236152	0.0007328	0.9763848	0.0007328	2.8155341°
73	0.0242218	0.0006626	0.9757782	0.0006626	2.8170803°
74	0.0248347	0.0005991	0.9751653	0.0005991	2.8186657°
75	0.0254537	0.0005417	0.9745463	0.0005417	2.8202886°
76	0.0260790	0.0004898	0.9739210	0.0004898	2.8219471°
77	0.0267103	0.0004429	0.9732897	0.0004429	2.8236397°
78	0.0273478	0.0004005	0.9726522	0.0004005	2.8253649°
79	0.0279912	0.0003622	0.9720088	0.0003622	2.8271216°
80	0.0286406	0.0003275	0.9713594	0.0003275	2.8289084°
81	0.0292959	0.0002962	0.9707041	0.0002962	2.8307244°
82	0.0299570	0.0002679	0.9700430	0.0002679	2.8325686°
83	0.0306240	0.0002422	0.9693760	0.0002422	2.8344402°
84	0.0312968	0.0002191	0.9687032	0.0002191	2.8363382°
85	0.0319752	0.0001981	0.9680248	0.0001981	2.8382620°
86	0.0326594	0.0001792	0.9673406	0.0001792	2.8402110°
87	0.0333492	0.0001621	0.9666508	0.0001621	2.8421844°
88	0.0340445	0.0001466	0.9659555	0.0001466	2.8441819°
89	0.0347454	0.0001326	0.9652546	0.0001326	2.8462028°
90	0.0354518	0.0001199	0.9645482	0.0001199	2.8482467°
91	0.0361636	0.0001084	0.9638364	0.0001084	2.8503132°
92	0.0368809	0.0000981	0.9631191	0.0000981	2.8524019°
93	0.0376034	0.0000887	0.9623966	0.0000887	2.8545125°
94	0.0383313	0.0000802	0.9616687	0.0000802	2.8566445°
95	0.0390645	0.0000726	0.9609355	0.0000726	2.8587978°
96	0.0398029	0.0000656	0.9601971	0.0000656	2.8609721°
97	0.0405464	0.0000594	0.9594536	0.0000594	2.8631670°
98	0.0412951	0.0000537	0.9587049	0.0000537	2.8653824°
99	0.0420488	0.0000486	0.9579512	0.0000486	2.8676181°
100	0.0428076	0.0000439	0.9571924	0.0000439	2.8698738°
101	0.0435714	0.0000397	0.9564286	0.0000397	2.8721494°
102	0.0443402	0.0000359	0.9556598	0.0000359	2.8744446°
103	0.0451139	0.0000325	0.9548861	0.0000325	2.8767594°
104	0.0458924	0.0000294	0.9541076	0.0000294	2.8790936°
105	0.0466758	0.0000266	0.9533242	0.0000266	2.8814471°
106	0.0474639	0.0000241	0.9525361	0.0000241	2.8838196°
107	0.0482568	0.0000218	0.9517432	0.0000218	2.8862112°
108	0.0490545	0.0000197	0.9509455	0.0000197	2.8886217°
109	0.0498567	0.0000178	0.9501433	0.0000178	2.8910509°
110	0.0506636	0.0000161	0.9493364	0.0000161	2.8934989°
111	0.0514751	0.0000146	0.9485249	0.0000146	2.8959654°
112	0.0522911	0.0000132	0.9477089	0.0000132	2.8984505°
113	0.0531116	0.0000119	0.9468884	0.0000119	2.9009540°
114	0.0539366	0.0000108	0.9460634	0.0000108	2.9034758°
115	0.0547659	0.0000098	0.9452341	0.0000098	2.9060160°
116	0.0555997	0.0000088	0.9444003	0.0000088	2.9085743°

Table 1: Continue

Shape and design parameters (λ, μ/μ_0, a, i, r) = (2, 8, 0.25, 1, 2)

g	α_1	β_2	$L(p_1)$	$L(p_2)$	(Theta)
117	0.0564378	0.0000080	0.9435622	0.0000080	2.9111508°
118	0.0572802	0.0000072	0.9427198	0.0000072	2.9137453°
119	0.0581269	0.0000065	0.9418731	0.0000065	2.9163579°
120	0.0589778	0.0000059	0.9410222	0.0000059	2.9189884°
121	0.0598328	0.0000053	0.9401672	0.0000053	2.9216369°
122	0.0606920	0.0000048	0.9393080	0.0000048	2.9243032°
123	0.0615554	0.0000044	0.9384446	0.0000044	2.9269873°
124	0.0624227	0.0000040	0.9375773	0.0000040	2.9296891°
125	0.0632942	0.0000036	0.9367058	0.0000036	2.9324087°
126	0.0641696	0.0000032	0.9358304	0.0000032	2.9351459°
127	0.0650489	0.0000029	0.9349511	0.0000029	2.9379008°
128	0.0659322	0.0000026	0.9340678	0.0000026	2.9406732°
129	0.0668194	0.0000024	0.9331806	0.0000024	2.9434632°
130	0.0677104	0.0000022	0.9322896	0.0000022	2.9462707°
131	0.0686052	0.0000020	0.9313948	0.0000020	2.9490956°
132	0.0695038	0.0000018	0.9304962	0.0000018	2.9519380°
133	0.0704062	0.0000016	0.9295938	0.0000016	2.9547978°
134	0.0713122	0.0000014	0.9286878	0.0000014	2.9576749°
135	0.0722219	0.0000013	0.9277781	0.0000013	2.9605693°
136	0.0731352	0.0000012	0.9268648	0.0000012	2.9634811°
137	0.0740521	0.0000011	0.9259479	0.0000011	2.9664101°
138	0.0749726	0.0000010	0.9250274	0.0000010	2.9693563°
139	0.0758966	0.0000009	0.9241034	0.0000009	2.9723197°
140	0.0768241	0.0000008	0.9231759	0.0000008	2.9753003°
141	0.0777551	0.0000007	0.9222449	0.0000007	2.9782981°
142	0.0786894	0.0000006	0.9213106	0.0000006	2.9813129°
143	0.0796272	0.0000006	0.9203728	0.0000006	2.9843449°
144	0.0805683	0.0000005	0.9194317	0.0000005	2.9873939°
145	0.0815128	0.0000005	0.9184872	0.0000005	2.9904600°
146	0.0824605	0.0000004	0.9175395	0.0000004	2.9935430°
147	0.0834115	0.0000004	0.9165885	0.0000004	2.9966431°
148	0.0843657	0.0000004	0.9156343	0.0000004	2.9997601°
149	0.0853230	0.0000003	0.9146770	0.0000003	3.0028941°
150	0.0862836	0.0000003	0.9137164	0.0000003	3.0060450°
151	0.0872472	0.0000003	0.9127528	0.0000003	3.0092127°
152	0.0882140	0.0000002	0.9117860	0.0000002	3.0123974°
153	0.0891838	0.0000002	0.9108162	0.0000002	3.0155989°
154	0.0901566	0.0000002	0.9098434	0.0000002	3.0188173°
155	0.0911325	0.0000002	0.9088675	0.0000002	3.0220524°
156	0.0921113	0.0000002	0.9078887	0.0000002	3.0253044°
157	0.0930930	0.0000001	0.9069070	0.0000001	3.0285732°
158	0.0940776	0.0000001	0.9059224	0.0000001	3.0318587°
159	0.0950651	0.0000001	0.9049349	0.0000001	3.0351609°
160	0.0960554	0.0000001	0.9039446	0.0000001	3.0384799°
161	0.0970486	0.0000001	0.9029514	0.0000001	3.0418155°
162	0.0980445	0.0000001	0.9019555	0.0000001	3.0451679°
163	0.0990432	0.0000001	0.9009568	0.0000001	3.0485369°
164	0.1000446	0.0000001	0.8999554	0.0000001	3.0519226°
165	0.1010486	0.0000001	0.8989514	0.0000001	3.0553250°
166	0.1020554	0.0000001	0.8979446	0.0000001	3.0587439°
167	0.1030647	0.0000001	0.8969353	0.0000001	3.0621795°

Bold value are significant values

Based on Table 1, the number of groups has different impact on α_1 and β_2. It shows that when the number of groups increases, the p_1 also increases. For instance, the α_1 is 0.0031546 and increases to 0.0085873 when the number of groups increases from 25-42. However, the β_2 does not follow the same pattern as α_1, since, Table 1 shows clearly that when the number of groups increases, the β_2 decreases. For example, the β_2 is 0.0984495 and decreases to 0.0157320 when the number of possible groups increases from 25-42.

Consequently, the changes on α_1 and β_2 also have different impact on the $L(\alpha_1)$ and $L(\beta_2)$. As illustrated in Table 1, the increment on α_1 contributes to the decrement on $L(\alpha_1)$. For instance, the $L(\alpha_1)$ decreases from 0.99685454-0.9914127 when the α_1 increases from 0.0031546-0.0085873. However, the β_2 does not have an impact on $L(\beta_2)$. In fact, the β_2 has exactly the same value as $L(\beta_2)$ which is both β_2 and $L(\beta_2)$ stand at 0.0984495 when the number of groups is 25.

The important finding is there are several number of possible groups range from 25-163 as shown in Table 1. The range (25-163) is considered as number of possible groups because it satisfies producer's and consumer's risks and in this study, both risks are set to be <0.1. For instance, the producer's and consumer's risks are 0.0031546 and 0.0984495, respectively, when the number of possible groups is 25. For any value outside the range, it cannot be considered as the number of possible groups because either one of the risks would be >0.1. For instance, 24 cannot be taken as the number of possible groups due to the fact that the consumer's risk is 0.1099953 which is >0.1 even though its producer's risk (0.0029132) is below 0.1. In fact, any value ≤24 has consumer's risk >0.1 as shown in Table 1. The same reason happens to 164 but this time 164 exceeds the producer' risk (0.1000446) meanwhile its consumer's risk (0.0000001) does not exceed 0.1. That is not just the case for 164 but any value ≥164 has producer's risk higher than 0.1.

In order to obtain the number of optimal groups, one more condition is imposed on the number possible groups which is it must have the smallest theta. Based on Table 1, it shows that the number of possible groups has different theta. For example, the theta are 3.0572103° and 3.0485369° when the number of possible groups are 25 and 163, respectively. From all the number of possible groups, 54 has the smallest theta (2.7984165°), therefore, this would make 54 as the number of optimal groups when the shape and design parameters are $(\lambda, \mu/\mu_0, a, i, r) = (2, 8, 0.25, 1, 2)$.

CONCLUSION

This study proposed an approach for finding number of optimal groups for GChSP by using minimum angle method. The approach was proposed, since, it was noticed that previous literatures related the minimum angle method did not really present the number of optimal groups. In fact, previous literatures only presented randomly number of possible groups that satisfied the conditions set in the minimum angle method which means number of possible groups did not necessarily represent the number of optimal groups. By using this suggested approach, researchers have clear insight on how actually to calculate the number of optimal groups and the number of optimal groups is only obtained when the angle created has the smallest value.

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