DOCUMENT RESUME

ED 110 519 TM 004 794

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TITLE A Note on Allocating Items to Subtests in Multiple Matrix Sampling.
INSTITUTION Southwest Regional Laboratory for Educational Research and Development, Los Alamitos, Calif.
REPORT NO SWRL-TM-3-72-05
PUB DATE 13 Jun 72
NOTE 19p.

EDRS PRICE MF-$0.76 HC-$1.58 PLUS POSTAGE
DESCRIPTORS *Item Sampling; *Matrices; *Sampling; *Standard Error of Measurement; *Statistical Analysis; Statistical Bias; Testing Problems
IDENTIFIERS Jackknife; *Multiple Matrix Sampling

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SOUTHWEST REGIONAL LABORATORY
TECHNICAL MEMORANDUM

DATE June 13, 1972

NO TM 3-72-05

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A NOTE ON ALLOCATING ITEMS TO SUBTESTS IN MULTIPLE MATRIX SAMPLING

David M. Shoemaker

Multiple matrix sampling or, more popularly, item-examinee sampling, is a procedure in which a set of *K* test items is subdivided randomly into *t* subtests containing *k* items each with each subtest administered to *n* examinees selected randomly from the population of *N* examinees. Although each examinee receives only a proportion of the *K* test items, the equations given by Hooke (1956) and Lord (1960) permit the researcher to estimate parameters of the test score distribution which would have been obtained by testing all *N* examinees over all *K* test items. Because numerous combinations of *t*, *k*, and *n* are feasible in any investigation, the researcher must come to grips with several questions about how the procedure should be implemented. "How should items be allocated to subtests?" is one important question requiring an answer and is the one addressed specifically herein; concomitantly, the feasibility of using the jackknife procedure for approximating standard errors of estimate in multiple matrix sampling is considered in some detail.

A basic requirement in multiple matrix sampling is that *k* items from the *K*-item population are allocated randomly to each subtest. However, in constructing the *t* subtests, four general item allocation procedures are possible--each of which is described more appropriately as <u>restricted random sampling</u>. The four procedures and concomitant restrictions are listed in Table 1 and an example of each procedure is given in Table 2 for *k* = 3 and *K* = 7.

Procedures 1, 2, and 3 are implemented easily in practice; Procedure 4, however, is more difficult and the degree of difficulty increases with increases in K. Within the context of the design of experiments, Procedures 3 and 4 are referred to, respectively, as a "partially balanced incomplete block" design (PBIB) and a "balanced incomplete block" design (BIB). That which is "partially balanced" or "balanced" by each design is the item pairings. In the BIB design, all possible item pairings occur among subtests and they occur with equal frequency; in the PBIB design, item pairings do not occur with equal frequency and, indeed, some item pairs may be excluded completely. A BIB design is often difficult to implement because, for a given K, no design may exist, or, if there is a design, the number of subtests required is excessively large. This limitation is most serious when K exceeds 50 even permitting minor adjustments in K to fit an available design. For example, when K = 91 and k = 10, 91 subtests would be required; for K = 97 and k = 10, 4656; and, for K = 199 and k = 10, 19701. The first of these three BIB designs is cited and illustrated by Cochran and Cox (1957); the other two are given by Ramanujacharyulu (1966) and cited by Knapp (1968a). Although BIB designs have been used on a few occasions (e.g., Knapp, 1968a, 1968b) when K was small (K = 43 and K = 12, respectively, with Knapp), such designs are ill-suited to large item populations. This point is of no minor import because one of the major reasons for using multiple matrix sampling is its potential for dealing with large item populations. Because of this, it is expected that the majority of item allocation procedures in multiple matrix sampling will involve Procedures 1, 2, or 3.

It should be noted that, in practice, Procedures 1, 2, and 3 are implemented typically in conjunction with item stratification, that is, a stratified-random sampling procedure is used with the stratification being on item content, item difficulty level or both item content and item difficulty level. The relative merits of such stratification procedures have been discussed previously (i.e., Shoemaker and Osburn, 1968; Kleinke, 1971) and are not considered here.

Of principal interest in this investigation were the relative merits of Procedures 1 and 3. Procedure 2 was excluded because it is used rarely in practice. The metric by which these two item allocation procedures were contrasted was the standard error of estimate.

METHOD

The research design was one of post mortem item-examinee sampling with the required data bases generated through a computer simulation model described previously by Shoemaker (1972). In post mortem item-examinee sampling, various samples of items and examinees are selected randomly from a data base (an item by examinee matrix) and used to estimate parameters of the base from which they have been sampled. The researcher acts as if only certain examinees have been tested over certain items knowing all the while the results which were obtained by testing all examinees over all items.

Parameters of the data base manipulated systematically were: (a) the number of test items ($\underline{K}$ = 40, 60), (b) variance of the item difficulty indices (σ_p^2 = .00, .05), and (c) degree of skewness in the normative distribution (distributed normally, markedly negatively-skewed).

When the test scores were negatively-skewed, only $\sigma_p^2 = 0$ was used. The reliability of the total scores was equal to .80 for all data bases generated. The 9 item-examinee sampling plans used are listed in Table 3. A PBIB design was used only when $\sigma_p^2 > 0$ for a given data base. When $\sigma_p^2 = 0$, all items are statistically parallel and Procedures 1 and 3 produce equivalent results (and all differences observed between the two procedures would be due to the sampling of examinees).

The parameters estimated were μ_1 (the mean test score), μ_2, μ_3, μ_4 (the second through fourth central moments) and σ_p^2. The equations used to estimate the moments of the test score distribution were those given by Lord (1960); σ_p^2 was estimated through a components of variance analysis. The results of each sampling plan were replicated 50 times.

Of additional concern in this investigation was a continued examination of the feasibility of the jackknife procedure in approximating standard errors of estimate in multiple matrix sampling. A description of the jackknife procedure and encouraging preliminary results in this area are given by Shoemaker (1972). In general, the jackknife operates on a data base which has been divided into subgroups of data and gives a mean estimate of the parameter computed over subgroups and an estimate of the standard error of estimate associated with this statistic. A basic component of the jackknife is the pseudovalue associated with each subgroup which, for each subgroup, is the weighted difference between the statistic computed on all the data and the statistic computed on the body of data which remains after omitting that subgroup. Because the pseudovalues are relatively independent of each other, the standard error of the statistic is computed according to the well-known formula for the standard error of a sample mean. If the statistics computed on each subgroup are weighted equally, the pseudovalues reduce algebraically to the averages for the subgroups. When the jackknife is applied to multiple matrix sampling there are $\underline{t}$ subgroups of data but only one score (the estimated parameter) for each subgroup with that statistic weighted according to the number of observations $\underline{tk}$ acquired by that subtest. The jackknife operates on the statistics obtained from one set of $\underline{t}$ subtests and approximates the variability of the pooled estimates which would have been observed over repeated replications of the design.

RESULTS

All results are reported in Tables 3 through 7. Because the entries in each Table are interpreted similarly, only those for one sampling plan in Table 3 will be described in detail. The first three entries in the first row of Table 3 give the parameters of the data base. In this case, the item population consisted of 40 items, the variance of the item difficulty indices (p = proportion answering the item correctly) was equal to 0 and the test scores were distributed normally. Using a ($\underline{t}$ = 4/$\underline{k}$ = 10/$\underline{n}$ = 50) item-examinee sampling plan with random allocation of items to subtests (Procedure 1 in Table 1) and replicating the sampling plan 50 times, the standard deviation of the 50 pooled estimates of the mean test score on the 40-item test was equal to .4695. Fifty jackknifed estimates of the standard error of the mean were produced. Their mean was equal to .4793; their standard deviation, .2445. If the items for each subtest had been allocated using a PBIB design (Procedure 3 in Table 1), corresponding results would have appeared under 'PBIB' in the first row. None are given there because $\sigma_p^2 = 0$ and the two item allocation procedures are equivalent.

Looking at the results for SE(R) across Tables 3 through 7, it is generally the case that, for each sampling plan, the standard error of estimate is less when a PBIB design is used. The relative magnitude of this discrepancy was greater for the mean test score and decreased sharply for successively higher central moments. Because several combinations of t and k (for a given tk) occurred among sampling plans, it was possible to examine the effect of certain combinations on the standard error of estimate. For a given tk, an increase in t resulted in a decrease in SE(R) when estimating the mean test score; for the second through fourth central moments, an increase in k resulted in a decrease in SE(R); and, for σ_p^2, no trend was discernable.

Regarding the jackknife, the results indicate that on the average it did approximate well standard errors of estimate. A major exception, and one noted previously by Shoemaker (1972), was found in estimating the standard error of the mean test score using a PBIB design where the jackknife consistently and markedly overestimated SE(R). However, the jackknife did approximate well the standard error here when a random sampling design was used to allocate items to subtests. Looking at the results across parameters, it was generally found that, when a PBIB design was used, the jackknife overestimated standard errors of estimate. This did not occur when a random sampling design (Procedure 1 in Table 1) was used. The relative discrepancy was most marked for the mean test score and decreased in magnitude for successively higher central moments.

In a manner similar to SE(R), the standard deviation of the jackknifed estimates of the standard error SD(J) decreased with increases in t when estimating the standard error of the mean test score and decreased generally with increases in k when estimating the standard errors of the higher central moments for a given tk.

DISCUSSION

The results support the conclusion that the procedure for allocating items to subtests in multiple matrix sampling is an important consideration. Specifically, a partially balanced incomplete block design is preferable to a random allocation for sampling plans having the same tk. The superiority of the PBIB is most apparent in estimating the mean test score and becomes less apparent in estimating higher central moments. This reinforces a conclusion made by Lord and Novick (1968) that in estimating the mean test score omitting even one item has a drastic effect on the standard error of estimate. In this investigation, a PBIB design guaranteed that each of the K items was included in some subtest. Such was not the case with a random item allocation where it was quite possible for certain items to be omitted completely (as happened to item 2 in Procedure 1 in Table 2). The results indicate that the Lord and Novick conclusion is applicable to higher central moments but the expected discrepancies are not as drastic as those expected with the mean test score.

Of additional interest in this investigation was the use of the jackknife in approximating standard errors of estimate in multiple matrix sampling. The results reinforce the conclusion drawn by

Shoemaker (1972) that the jackknife can be used for this purpose and also shed light on a problem mentioned therein. Shoemaker noted that the jackknife overestimated the standard error of the mean test score when $\sigma_p^2 \doteq .05$ and items were allocated to subtests using a PBIB design. The results in Table 3 suggest that the inability of the jackknife to perform well in this case was a function of the item allocation procedure. For the jackknife to be appropriate, the pseudovalues must be independent and the results suggest that this requirement is violated with a PBIB design. Regarding this violation, the jackknife is not as robust when estimating the standard error of the mean test score as it is in estimating standard errors of higher central moments. The conclusion seems warranted that, when σ_p^2 departs significantly from zero and a PBIB design is used to allocate items to subtests, the jackknife will approximate conservatively the standard error of estimate in multiple matrix sampling.

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TABLE 1

Procedures for Allocating Items to Subtests in Multiple Matrix Sampling

Item Allocation Procedure	Restrictions On tk	Restrictions On Sampling Of Items
1. Random Sampling	None	Without replacement within each subtest With replacement among subtests
2. Partially Balanced Incomplete Block Design (not all items tested)	tk < K	Without replacement within each subtest Without replacement among subtests
3. Partially Balanced Incomplete Block Design (all items tested)	tk ≥ K tk = rK (r integer)	Without replacement within each subtest Each of the K items appears with equal frequency (r) among subtests
4. Balanced Incomplete Block Design	tk ≥ K tk = rK (r integer) $tk = \frac{K(K-1)\lambda}{k-1}$ (λ integer)	Without replacement within each subtest Each of the K(K - 1)/2 item pairings appears with equal frequency (λ) among subtests

TABLE 2

Examples of Subtests Resulting From the Four Item Allocation Procedures Described in Table 1 Using k = 3 and K = 7

Subtest Number	Procedure 1	Procedure 2	Procedure 3	Procedure 4
1	1 3 5	1 2 3	1 2 3	1 2 4
2	3 4 5	4 5 6	4 5 6	2 3 5
3	1 3 5		7 1 2	3 4 6
4	1 4 7		3 4 5	4 5 7
5	4 5 6		6 7 1	5 6 1
6	3 4 6		2 3 4	6 7 2
7	3 6 7		5 6 7	7 1 3

Table 3

Standard Errors Of Estimate For μ_1 As A Function Of K, σ_p^2 And Degree Of Skewness In Normative Distribution For Selected Sampling Plans Using Two Item-Allocation Procedures

Degree of Skewness In Normative Distribution	K	σ_p^2	Sampling Plan (t/k/n)	Random Allocation SE(R)	Random Allocation MN(J)	Random Allocation SD(J)	PBIB SE(R)	PBIB MN(J)	PBIB SD(J)
Normal	40	.00	(04/10/50)	.4695	.4795	.2445			
			(08/10/50)	.3421	.3487	.1238			
			(12/10/50)	.3141	.3242	.0890			
			(10/04/50)	.3871	.3948	.1258			
		.05	(04/10/50)	1.5477	1.2802	.6016	.4030	1.4623	.4959
			(08/10/50)	.8547	.9318	.2176	.3688	.9339	.2476
			(12/10/50)	.8539	.7474	.1509	.2963	.8454	.1506
			(10/04/50)	1.4660	1.3748	.3469	.3475	1.5271	.2657
	60	.00	(06/10/50)	.6474	.5889	.2319			
			(12/10/50)	.3999	.4002	.1159			
			(18/10/50)	.2815	.3057	.0628			
			(10/06/50)	.5043	.4595	.1479			
			(10/18/50)	.4831	.3853	.1019			
		.05	(06/10/50)	1.7968	1.7133	.5550	.6181	1.8427	.4875
			(12/10/50)	1.1683	1.1441	.2121	.3550	1.1650	.2622
			(18/10/50)	1.0170	.9547	.1710	.3001	.9328	.1566
			(10/06/50)	1.6451	1.7862	.4223	.5444	1.7093	.3135
			(10/18/50)	.9840	.8627	.2195	.3607	1.3160	.2781
Negatively Skewed	40	.00	(04/10/50)	.4454	.3565	.1808			
			(08/10/50)	.3082	.2611	.0914			
			(12/10/50)	.2753	.2399	.0570			
			(10/04/50)	.3657	.3188	.1183			
	60	.00	(06/10/50)	.4077	.4186	.1742			
			(12/10/50)	.3062	.3204	.0807			
			(18/10/50)	.2646	.2836	.0656			
			(10/06/50)	.4213	.3823	.1186			
			(10/18/50)	.3588	.3251	.0967			

Table 4

Standard Errors Of Estimate For μ_2 As A Function Of K, σ_p^2 And Degree Of Skewness In Normative Distribution For Selected Sampling Plans Using Two Item Allocation Procedures

Degree of Skewness In Normative Distribution	K	σ_p^2	Sampling Plan (t/k/n)	Random Allocation SE(R)	Random Allocation MN(J)	Random Allocation SD(J)	PBIB SE(R)	PBIB MN(J)	PBIB SD(J)
Normal	40	.00	(04/10/50)	10.3190	11.1584	5.7984			
			(08/10/50)	8.4280	8.1964	2.4210			
			(12/10/50)	7.2476	6.6786	1.9780			
			(10/04/50)	25.0248	23.0188	7.1526			
		.05	(04/10/50)	7.9539	8.9085	3.4973	7.1495	7.8056	3.1068
			(08/10/50)	6.6268	5.9696	1.9546	4.3141	5.5723	1.6081
			(12/10/50)	5.3812	5.1389	1.5443	3.7071	4.9847	1.1616
			(10/04/50)	9.7860	10.7747	2.7205	8.6920	11.4619	3.8258
	60	.00	(06/10/50)	25.6763	22.1921	8.6872			
			(12/10/50)	19.6631	18.4521	6.5854			
			(18/10/50)	16.6729	14.1373	3.9119			
			(10/06/50)	33.0618	32.5629	11.6935			
			(10/18/50)	10.0443	9.1222	2.7066			
		.05	(06/10/50)	12.5992	11.8214	4.7175	10.9600	13.3160	5.3499
			(12/10/50)	10.3995	9.7892	2.1409	7.6493	9.5244	?.7857
			(18/10/50)	8.6830	8.3365	1.9409	5.7198	8.3856	1.6831
			(10/06/50)	16.3602	16.3580	5.9341	15.1729	15.5876	5.8778
			(10/18/50)	7.2842	7.1261	2.0668	6.1346	10.4181	2.8439
Negatively Skewed	40	.00	(04/10/50)	8.1275	7.0332	2.9720			
			(08/10/50)	5.9043	5.2687	1.5521			
			(12/10/50)	3.8652	4.5914	1.0571			
			(10/04/50)	11.0677	11.4673	3.2327			
	60	.00	(06/10/50)	10.4518	12.6290	4.8652			
			(12/10/50)	7.7333	9.2427	2.2513			
			(18/10/50)	7.0408	7.9627	1.8957			
			(10/06/50)	15.4877	16.3723	4.4385			
			(10/18/50)	7.7647	7.5323	2.6283			

Table 5

Standard Errors Of Estimate For μ_3 As A Function Of K, σ_p^2 And Degree Of Skewness In Normative Distribution For Selected Sampling Plans Using Two Item Allocation Procedures

Degree of Skewness In Normative Distribution	K	σ_p^2	Sampling Plan (t/k/n)	Random Allocation SE(R)	Random Allocation MN(J)	Random Allocation SD(J)	PBIB SE(R)	PBIB MN(J)	PBIB SD(J)
Normal	40	.00	(04/10/50)	95.4697	82.1234	30.7325			
			(08/10/50)	58.3290	52.2556	16.7539			
			(12/10/50)	54.7119	46.4031	11.5517			
			(10/04/50)	154.3063	158.9480	40.9214			
		.05	(04/10/50)	92.4112	82.2875	56.5522	81.0209	90.1830	39.0318
			(08/10/50)	63.9500	59.0365	20.8718	52.0875	53.5022	18.2656
			(12/10/50)	54.5546	48.4806	15.3487	44.9722	44.7820	10.6245
			(10/04/50)	150.5844	134.9008	49.1399	157.6452	157.2014	58.9603
	60	.00	(06/10/50)	235.6356	200.1025	79.9695			
			(12/10/50)	152.3726	136.6384	35.9859			
			(18/10/50)	97.2519	117.7001	33.0509			
			(10/06/50)	295.9319	243.6418	63.5954			
			(10/18/50)	84.1298	97.9192	26.7073			
		.05	(06/10/50)	211.1189	180.5808	81.7222	202.0558	187.9444	78.6910
			(12/10/50)	105.5673	113.3641	36.1784	143.5422	221.6948	36.2300
			(18/10/50)	106.5512	106.5320	26.0576	96.4460	104.7214	22.4361
			(10/06/50)	296.5659	274.6514	127.4005	205.3775	348.0962	88.7696
			(10/18/50)	99.9720	85.2712	28.1157	99.1311	106.7550	37.2340
Negatively Skewed	40	.00	(04/10/50)	169.2486	135.8661	72.2757			
			(08/10/50)	124.0299	90.6094	32.3440			
			(12/10/50)	75.4386	81.5741	26.2247			
			(10/04/50)	166.1067	180.5012	65.9801			
	60	.00	(06/10/50)	283.8396	262.1475	125.9281			
			(12/10/50)	162.3083	197.1463	60.8031			
			(18/10/50)	188.7637	163.7913	50.8795			
			(10/06/50)	318.8521	299.8196	127.8573			
			(10/18/50)	207.6684	178.5717	86.1557			

Table 6

Standard Errors Of Estimate For μ_4 As A Function Of K, σ_p^2 And Degree Of Skewness In Normative Distribution For Selected Sampling Plans Using Two Item Allocation Procedures

Degree of Skewness In Normative Distribution	K	σ_p^2	Sampling Plan (t/k/n)	Random Allocation SE(R)	Random Allocation MN(J)	Random Allocation SD(J)	PBIB SE(R)	PBIB MN(J)	PBIB SD(J)
Normal	40	.00	(04/10/50)	2464.1028	2367.5225	1212.0820			
			(08/10/50)	2113.4199	1796.8948	786.4529			
			(12/10/50)	1774.4221	1529.3450	620.9302			
			(10/04/50)	16045.2227	13543.6289	3169.3379			
		.05	(04/10/50)	1883.2766	1820.5398	1050.4209	1653.7188	1613.2598	875.7251
			(08/10/50)	1281.1035	1212.9401	504.7688	1093.6416	1141.0798	446.8242
			(12/10/50)	973.3289	991.1028	347.4119	838.4304	998.6802	274.5200
			(10/04/50)	4237.8984	4235.0703	1377.8181	4722.1680	5449.7969	2078.9905
	60	.00	(06/10/50)	10950.5273	9623.3086	5453.0313			
			(12/10/50)	9842.6406	7361.3281	4669.5977			
			(18/10/50)	7037.5742	5681.0117	2974.5803			
			(10/06/50)	24526.7383	21178.6992	10410.3398			
			(10/18/50)	4223.4453	3607.2349	1448.7485			
		.05	(06/10/50)	4555.6914	4434.7070	2073.8750	4860.4805	4699.3086	2399.4175
			(12/10/50)	3635.8464	3582.2712	1374.7026	3847.7754	3657.5723	1602.8821
			(18/10/50)	3339.9836	3164.2874	1255.7400	3055.2769	3054.3074	944.7239
			(10/06/50)	10614.8945	9858.2930	6031.3594	7368.3516	8366.3164	3743.1499
			(10/18/50)	2374.1726	2384.8635	972.7341	2870.6550	3721.7036	1476.2563
Negatively Skewed	40	.00	(04/10/50)	5136.1914	4004.5249	2548.0661			
			(08/10/50)	3318.4131	2509.2000	1099.3921			
			(12/10/50)	2263.2507	2353.1648	893.5596			
			(10/04/50)	6031.0977	5852.6328	2310.6248			
	60	.00	(06/10/50)	11297.3759	9335.6484	6168.7227			
			(12/10/50)	6825.1914	7587.3711	3559.4587			
			(18/10/50)	7550.9961	6172.3945	2761.5332			
			(10/06/50)	14444.2734	11494.5703	6548.7461			
			(10/18/50)	9004.3203	7050.9453	4422.8242			

Table 7

Standard Errors Of Estimate For σ_p^2 As A Function Of K, σ_p^2 And Degree Of Skewness In Normative Distribution For Selected Sampling Plans Using Two Item Allocation Procedures

Degree of Skewness In Normative Distribution	K	σ_p^2	Sampling Plan (t/k/n)	Random Allocation			PBIB		
				SE(R)	MN(J)	SD(J)	SE(R)	MN(J)	SD(J)
Normal	40	.00	(04/10/50)	.0009	.0010	.0006			
			(08/10/50)	.0011	.0008	.0005			
			(12/10/50)	.0010	.0009	.0004			
			(10/04/50)	.0012	.0011	.0006			
		.05	(04/10/50)	.0111	.0097	.0038	.0059	.0108	.0050
			(08/10/50)	.0088	.0074	.0022	.0044	.0077	.0023
			(12/10/50)	.0080	.0067	.0012	.0041	.0064	.0013
			(10/04/50)	.0134	.0117	.0029	.0076	.0136	.0036
	60	.00	(06/10/50)	.0011	.0009	.0006			
			(12/10/50)	.0010	.0008	.0004			
			(18/10/50)	.0006	.0006	.0002			
			(10/06/50)	.0012	.0009	.0005			
			(10/18/50)	.0007	.0006	.0003			
		.05	(06/10/50)	.0102	.0084	.0032	.0054	.0098	.0034
			(12/10/50)	.0057	.0059	.0014	.0044	.0061	.0014
			(18/10/50)	.0048	.0047	.0038	.0034	.0051	.0008
			(10/06/50)	.0082	.0098	.0027	.0048	.0100	.0023
			(10/18/50)	.0054	.0047	.0011	.0041	.0054	.0011
Negatively Skewed	40	.00	(04/10/50)	.0013	.0007	.0007			
			(08/10/50)	.0011	.0007	.0006			
			(12/10/50)	.0007	.0007	.0003			
			(10/04/50)	.0011	.0010	.0007			
	60	.00	(06/10/50)	.0008	.0005	.0004			
			(12/10/50)	.0006	.0005	.0002			
			(18/10/50)	.0007	.0005	.0003			
			(10/06/50)	.0008	.0006	.0005			
			(10/18/50)	.0006	.0005	.0003			

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