The fine structure of (v,3) directed triple systems: $v \equiv 0$ or $1 \pmod{3}$

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ABSTRACT. The fine structure of a directed triple system of index λ is the vector $(c_1, c_2, \ldots, c_{\lambda})$, where c_i is the number of directed triples appearing precisely i times in the system. We determine necessary and sufficient conditions for a vector to be the fine structure of a directed triple system of index 3 for $v \equiv 0$ or 1 (mod 3).

1 Introduction and definitions

Let a, b and c be three distinct elements. A transitive or directed triple (a,b,c) is a set of three ordered pairs of the form $\{(a,b),(b,c),(a,c)\}$. A directed triple system of order v and index λ , or (v,λ) DTS, is a pair (V,\mathcal{D}) . Here V is a v-set of elements, and \mathcal{D} is a collection of directed triples (called blocks) on V, with the property that every ordered pair (x,y) of elements of V appears in precisely λ of the directed triples. Directed triple systems have been studied extensively, often under the name "transitive triple systems". The necessary condition for a (v,λ) DTS to exist is simply that the number of ordered pairs $\lambda v(v-1)$ occurring in blocks be divisible by three. Hence, we require $v \equiv 0$, 1 (mod 3) for $\lambda \equiv 1$, 2 (mod 3), and we require only $v \neq 2$ for $\lambda \equiv 0 \pmod{3}$. It is well-known that these conditions are also sufficient for the existence of (v,λ) DTSs (see Colbourn and Rosa [6] for a recent survey).

The fine structure of a directed triple system of index λ is the vector $(c_1, c_2, \ldots, c_{\lambda})$, where c_i is the number of directed triples appearing precisely i times in the system. Colbourn, Mathon, Rosa and Shalaby [4] determined the fine structure of threefold triple systems for $v \equiv 1$ or 3 (mod 6), and

Colbourn, Mathon and Shalaby [5] determined the fine structure of three-fold triple systems for $v \equiv 5 \pmod{6}$. In [7] the author found the fine structure of balanced ternary designs with block size 3, index 3 and $\rho_2 = 3$.

It is easy to determine the fine structure of (v,2) DTSs. Let (V,\mathcal{D}) and (V,\mathcal{D}') be two (v,1) DTS having exactly m directed triples in common, where $m \in \{0,1,2,3,\ldots,v(v-1)/3\} \setminus \{(v(v-1)/3)-1\}$; see [9]. Then $(V,\mathcal{D}\cup\mathcal{D}')$ is a (v,2) DTS with exactly m doubly repeated blocks. Moreover there does not exist a (v,2) DTS with exactly (v(v-1)/3)-1 doubly repeated blocks. Therefore the vector (c_1,c_2) is a fine structure of a (v,2) DTS if and only if $0 \le c_2 \le (v(v-1)/3)$, $c_2 \ne (v(v-1)/3)-1$, and $c_1 + 2c_2 = 2v(v-1)/3$.

In this paper we study the fine structure of (v,3) DTSs. Indeed, we determine the necessary and sufficient conditions for a vector to be the fine structure of a directed triple system of index 3 for $v \equiv 0$ or 1 (mod 3). Since any two of $\{c_1, c_2, c_3\}$ determine the third, we use a more convenient notation for the fine structure: (t,s) is said to be the fine structure of a (v,3) DTS if $c_2 = t$ and $c_3 = v(v-1)/3 - s$ (note that v(v-1)/3 is an integer since $v \equiv 0$, 1 (mod 3)). We first need to know the pairs (t,s) which can possibly arise as fine structures. We define $Adm(v) = \{(t,s)|0 \le t \le s \le v(v-1)/3\} \setminus \{(0,1),(1,1),(1,2),(1,3)\}$, and use the notation Fine(v) for the set of fine structures which actually arise in (v,3) DTSs. Our result is as follows.

Main Theorem:

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Fine(4) = Adm(4) \setminus \{(0,2), (0,3)\},\

Fine(6) = Adm(6) \setminus \{(0,2), (0,3), (0,4), (1,4)\},\

Fine(7) = Adm(7) \setminus \{(0,3), (1,4), (0,5)\} and

Fine(v) = Adm(v) for all v \equiv 0, 1 \pmod{3}, v \notin \{4,6,7\}.
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An argument similar to that used in Lemma 2.1 of [4] or Lemma 1.1 of [7] leads to the following result.

Lemma 1.1. If
$$(t,s) \in Fine(v)$$
 then $0 \le t \le s \le v(v-1)/3$.

Lemma 1.2. $Fine(v) \subseteq Adm(v)$.

Proof: We must only eliminate the cases (0,1), (1,1), (1,2) and (1,3). Let (V,\mathcal{D}) be a (v,3) DTS of type (1,3). Let H be the simple directed graph whose edges are the ordered pairs of elements of V which do not appear in a three times repeated block. Let G be the graph H without direction on edges (the underlying graph). Note that G can have at most two edges between any two distinct vertices. Obviously |E(G)| = 9 and all vertices of G have even degree. Since 3H can be decomposed into directed triples so that none are repeated three times and precisely one is repeated twice it follows that G cannot have more than one vertex of degree two. Therefore G is isomorphic to one of the following graphs in figure 1.

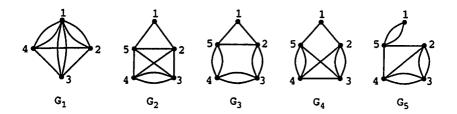


Figure 1

An exhaustive computer search shows that if H is a directed graph whose underlying graph is G_i (above) then 3H cannot be decomposed into directed triples so that none are repeated three times and precisely one is repeated twice. So $(1,3) \notin Fine(v)$. A similar method shows that (0,1), (1,1) and (1,2) are not in Fine(v).

We make use of pairwise balanced designs and group divisible designs in the next section. A pairwise balanced design $((v, K, \lambda) \text{ PBD})$ is a collection of subsets of size $k \in K$, called blocks, chosen from a set of v elements in such a way that every pair of elements belongs to λ blocks. A group divisible design, $\text{GDD}(K, \lambda, M; v)$, is a collection of subsets of size $k \in K$, called blocks, chosen from a v-set, where the v-set is partitioned into disjoint subsets (called groups) of size $m \in M$ such that each block contains at most one element from each group, and any two elements from distinct groups occur together in λ blocks. If $M = \{m\}$ and $K = \{k\}$ we write $\text{GDD}(k, \lambda, m; v)$. Note that if a GDD(K, 1, M; v) exists then a $(v, \{k | k \in K\} \cup \{m | m \in M\}, 1)$ PBD exists.

2 Construction

In this section we show that Fine(v) = Adm(v) for all $v \equiv 0, 1 \pmod{3}$, $v \geq 15$.

Lemma 2.1. $(n,n) \in Fine(v)$ for all $0 \le n \le v(v-1)/3$ and $n \ne 1$.

Proof: Let (V, \mathcal{D}) and (V, \mathcal{D}') be two (v, 1) DTSs with exactly m blocks in common, where $m \in \{0, 1, 2, \ldots, v(v-1)/3\} \setminus \{(v(v-1)/3) - 1\}$; (see [9]). Then $(V, \mathcal{D} \cup \mathcal{D} \cup \mathcal{D}')$ is a (v, 3) DTS with fine structure ((v(v-1)/3) - m, (v(v-1)/3) - m).

Now we examine Fine(v) for v = 3, 4 and 6.

Lemma 2.2. $Fine(3) = \{(0,0), (0,2), (2,2)\}.$

Proof: Let $\mathcal{D} = \{(1,2,3), (3,2,1), (1,3,2), (2,3,1), (2,1,3), (3,1,2)\}$. Then \mathcal{D} yields a (3,3) DTS of type (0,2) on $\{1,2,3\}$. Now the result follows from Lemma 1.2 and Lemma 2.1.

Lemma 2.3. $Fine(4) = Adm(4) \setminus \{(0,2), (0,3)\}.$

Proof: We apply Lemma 2.1 for the types (0,0), (2,2), (3,3) and (4,4). Then we use Designs 1-5 in [8] for the types (0,4), (1,4), (2,4), (3,4) and (2,3). Moreover an exhaustive search shows that (0,2), $(0,3) \notin Fine(4)$. \square

Lemma 2.4. $Fine(6) = Adm(6) \setminus \{(0,2), (0,3), (0,4), (1,4)\}.$

Proof: First we show that (0, 2), (0, 3), (0, 4) and (1, 4) are not in Fine(6). Let (V, \mathcal{D}) be a (6,3) DTS of type (t, s), where $(t, s) \in \{(0, 2), (0, 3), (0, 4), (1, 4)\}$. Let H be the simple directed graph whose edges are the ordered pairs of elements of V which do not appear in a three times repeated block. Let G be the graph H without direction on edges. Note that G can have at most two edges between any two distinct vertices. Obviously all vertices of G have even degree. Moreover, if t=0 then G cannot have a vertex of degree two and if t=1 then G can have at most one vertex of degree two. An exhaustive computer search shows that when (t,s)=(0,2) or (0,3), in each case there is exactly one candidate for G; when (t,s)=(0,4) there are exactly 22 candidates for G, and when (t,s)=(1,4) there are exactly 60 candidates for G (up to isomorphism). Checking each of these candidates exhaustively shows that (0,2), (0,3), (0,4) and (1,4) are not in Fine(6).

Secondly we apply Lemma 2.1 and Designs 6-53 in [8].

Lemma 2.5. Let $v \equiv 1$ or 3 (mod 6) and $v \ge 15$. Then there exists a $(v, \{3,4,6\}, 1)$ PBD with exactly one block of size 6, six blocks of size 4 and (v(v-1)/6) - 17 blocks of size 3.

Proof: Let $w \in \{15, 19, 21, 25, 27, 31, 33\}$ and let (W, \mathcal{B}_i) , $1 \leq i \leq 7$, be Design i in Appendix 1, where $W = \{1, 2, 3, \ldots, w\}$. We define $\mathcal{B} = \{\{1, 2, 3, 4, 5, 6\}, \{1, 7, 8, 9\}, \{2, 7, 10, 11\}, \{3, 8, 12, 13\}, \{4, 9, 14, 15\}, \{5, 10, 12, 14\}, \{6, 11, 13, 15\}\}$. Then $(W, \mathcal{B} \cup \mathcal{B}_i)$ is a $(w, \{3, 4, 6\}, 1)$ PBD with the required structure. Now let $v \geq 37$. It is well-known that there exists a (v, 3, 1) BIBD having a (w, 3, 1) BIBD as a subdesign, where $w \in \{15, 19, 21, 25, 27, 31, 33\}$. Now if we place a $(w, \{3, 4, 6\}, 1)$ PBD (constructed above) on the elements of the subdesign then the resulting design is a $(v, \{3, 4, 6\}, 1)$ PBD with the required structure. This completes the proof.

Lemma 2.6. There exist a $(v, \{3, 4, 6\}, 1)$ PBD with at least one block of size 3, one block of size 4 and one block of size 6 for all $v \equiv 0$ or 4 (mod 6), $v \ge 18$.

Proof: Let $v \equiv 4 \pmod{6}$, $v \geq 22$. Then there exists a GDD(3, 1, $\{6, 4^*\}; v$) (with exactly one group of size 4); see [3]. Therefore there exists a $(v, \{3, 4^*, 6\}, 1)$ PBD with the required structure.

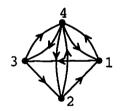
Now let $v \equiv 0 \pmod 6$. We take a GDD(4, 1, $\{2,5^*\}$; 6n + 5) which exists for $n \geq 3$ (see [2]). By adding a new point ∞ to the groups of this design we can construct a $(v, \{3,4,6^*\},1)$ PBD with the required structure, where $v \equiv 0 \pmod 6$, $v \geq 24$. For v = 18 we proceed as follows. Let \mathcal{B} be the blocks of Design 8 in Appendix 1 and let $\mathcal{B}' = \{\{1,2,3,4,5,6\},\{7,8,9,10\},\{11,12,13,14\},\{15,16,17,18\}\}$. Then $\mathcal{B} \cup \mathcal{B}'$ yields a $(18,\{3,4,6^*\},1)$ PBD on $\{1,2,3,\ldots,18\}$. This completes the procof.

Lemma 2.7. $Adm(v) \setminus \{(0,3)\} \subseteq Fine(v) \text{ for all } v \equiv 1 \text{ or } 3 \pmod{6}, v \geq 15, \text{ and for all } v \equiv 0 \text{ or } 4 \pmod{6}, v \geq 18.$

Proof: Let (V, \mathcal{B}) be a $(v, \{3, 4, 6\}, 1)$ PBD which we obtain from Lemma 2.5 or Lemma 2.6. For each block $B \in \mathcal{B}$ we place the triples of a (|B|, 3) DTS on the elements of B. The result is a (v, 3) DTS. Using DTSs with different types (see Lemmas 2.2, 2.3 and 2.4) on each block of the PBD we find that $Adm(v) \setminus \{(0, 3)\} \subseteq Fine(v)$

Lemma 2.8. $(0,3) \in Fine(v)$ for $v \equiv 0, 1 \pmod{3}, v \geq 9$.

Proof: Let G be the following directed graph.



Then 3G can be decomposed into nine directed triples $\mathcal{D} = \{(1,3,4), (1,4,3), (2,1,4), (2,4,1), (3,2,4), (3,4,2), (4,1,3), (4,2,1), (4,3,2)\}$. Now let \mathcal{D}_i , $1 \le i \le 7$, be the blocks of Designs 1-7 in Appendix 2. Then $(W, \mathcal{D} \cup \mathcal{D}_i \cup \mathcal{D}_i \cup \mathcal{D}_i)$ is a (w,3) DTS of type (0,3), where $w \in \{9,10,12,13,15,16,18\}$ and $W = \{1,2,3,\ldots,w\}$. Now let $v \ge 19$. It is well-known that there exists a (v,1) DTS having a (w,1) DTS as a subdesign, where $w \in \{9,10,12,13,15,16,18\}$; see e.g. [1]. Triplicate each directed triple of the (v,1) DTS which is not in the subdesign, and then place a (w,3) DTS of type (0,3) on the elements of the subdesign. The result is a (v,3) DTS of type (0,3). This completes the proof.

Lemma 2.9. Fine(16) = Adm(16).

Proof: We add a new point ∞ to the groups of a GDD(3,1,5; 15), which exists (see [3]), to obtain a (16, {3,6},1) PBD. Now using a method similar to that described in Lemma 2.7 we obtain $Adm(16) \setminus \{(0,3),(1,4)\} \subseteq Fine(16)$. For the type (1,4) we take a (16,4,1) BIBD and place (4,3) DTSs with type (0,0) on the elements of each block of the design except one block which we place a (4,3) DTS with type (1,4). Finally we apply Lemma 2.8 for the type (0,3).

So far we have proved the following result.

Theorem 2.10. Fine(v) = Adm(v) for $v \equiv 0, 1 \pmod{3}$, v = 3 or $v \ge 15$.

3 Solutions for small orders

In this section we examine Fine(v) for v = 7, 9, 10, 12 and 13. We show that $Fine(7) = Adm(7) \setminus \{(0,3), (1,4), (0,5)\}$ and Fine(v) = Adm(v) for v = 9, 10, 12 and 13.

Lemma 3.1. If there exists a (v, 3, 3) BIBD of type (t_1, s_1) and a (v, 3, 3) BIBD of type (t_2, s_2) then there exists a (v, 3) DTS of type (t_1+t_2, s_1+s_2) .

Proof: Let $(\mathbf{Z}_v, \mathcal{B}_i)$ be a (v, 3, 3) BIBD of type (t_i, s_i) , i = 1, 2 (see [4] and [5] for the fine structure of (v, 3, 3) BIBDs). Without loss of generality we can assume a < b < c for each block $\{a, b, c\} \in \mathcal{B}_1$ and d > e > f for each block $\{d, e, f\} \in \mathcal{B}_2$. Form $\mathcal{D} = \{(a, b, c) | \{a, b, c\} \in \mathcal{B}_1\} \cup \{(d, e, f) | \{d, e, f\} \in \mathcal{B}_2\}$. Then $(\mathbf{Z}_v, \mathcal{D})$ is a (v, 3) DTS of type $(t_1 + t_2, s_1 + s_2)$.

Lemma 3.2. Let $v, w \equiv 0, 1 \pmod{3}$. If there exists a (v, 1) DTS having a (w, 1) DTS as a subdesign then $Fine(w) \subseteq Fine(v)$.

Proof: Triplicate each directed triple of the (v, 1) DTS which is not in the subdesign, and then place a (w, 3) DTS on the elements of the subdesign.

Lemma 3.3. $Fine(7) = Adm(7) \setminus \{(0,3), (1,4), (0,5)\}.$

Proof: First we show that (0,3), (1,4) and (0,5) are not in Fine(7). Let (V,\mathcal{D}) be a (7,3) DTS of type (t,s), where $(t,s) \in \{(0,3),(1,4),(0,5)\}$. Let H and G be the graphs defined in Lemma 2.4. An exhaustive computer search shows that when (t,s)=(0,3) there is exactly one candidate for G, when (t,s)=(1,4) there are exactly 60 candidates for G and when (t,s)=(0,5) there are exactly 180 candidates for G (up to isomorphism). Checking each of these candidates exhaustively shows that (0,3), (1,4) and (0,5) are not in Fine(7). Secondly we apply Lemma 2.1 for the types of the form (n,n), $0 \le n \le 14$, $n \ne 1$. Thirdly we take a (7,3,1) BIBD and place (3,3) DTSs with different types on the elements of the blocks of the design to obtain (7,3) DTSs with types of the form (2n,2m), $0 \le n$, $m \le 7$.

Finally we apply Lemma 3.1 with v = 7 (see [4] for the fine structure of a (7,3,3) BIBD). For the remaining types see Designs 54-100 in [8].

Lemma 3.4. Fine(9) = Adm(9).

Proof: First we apply Lemma 2.1 for the types of the form (n,n), $0 \le n \le 24$, $n \ne 1$. Secondly we take a (9,3,1) BIBD and place (3,3) DTSs with different types on the elements of the blocks of the design to obtain (9,3) DTSs with types of the form (2n,2m), $0 \le n$, $m \le 12$. Thirdly we apply Lemma 3.1 with v = 9 (see [4] for the fine structure of a (9,3,3) BIBD). For the type (0,3) we use Lemma 2.8 and for the types (2,3), (1,4) and (3,4) we apply Lemma 3.2 (note that there exists a (9,1) DTS having a (4,1) DTS as a subdesign; see e.g. [1]). The remaining types are settled by Designs 101-159 in [8].

Lemma 3.5. Fine(10) = Adm(10).

Proof: We take a $(10, \{3, 4\}, 1)$ PBD and place the triples of a (4,3) DTS or a (3,3) DTS on the elements of each block of size 4 or 3. Using DTSs with different types covers all the types of Fine(10) except the types $(t, s) \in \{(i, 2j + 1)|i = 0, 1 \text{ and } 2 \le j \le 14\} \cup \{(0, 3)\}$. The type (0,3) is covered by Lemma 2.8 and the remaining types are settled by Designs 160-185 in [8].

Lemma 3.6. Fine(12) = Adm(12).

Proof: Since there exists a GDD(3,1,4; 12) it follows that there exists a (12, {3,4}, 1) PBD. Now a method similar to that described in Lemma 3.5 covers all the types of Fine(12) except the types $(t, s) \in \{(i, 2j+1)|i=0, 1 \text{ and } 2 \le j \le 21\} \cup \{(0,3)\}$. The type (0,3) is covered by Lemma 2.8 and the remaining types are settled by Designs 186-225 in [8].

Lemma 3.7. Fine(13) = Adm(13).

Proof: Since there exists a (13,1) DTS containing a (6,1) DTS as a subdesign (see e.g. [1]) it follows that $Fine(6) \subseteq Fine(13)$ (see Lemma 3.2). We take a (13,3,1) BIBD and place (3,3) DTSs with different types on the elements of each block of the design to obtain (13,3) DTSs with types of the form (2n, 2m), $0 \le n$, $m \le 26$. We also apply Lemma 3.1 with v = 13 (see [4] for the fine structure of a (13,3,3) BIBD). The remaining types are (0,3), (1,4) and (0,11). For the type (0,3) we apply Lemma 2.8 and for the type (1,4) we take a (13,4,1) BIBD and place (4,3) DTSs with type (0,0) on the elements of each block of the BIBD except one block which we place a (4,3) DTS with type (1,4). Finally we use Design 226 in [8] for the type (0,11). This completes the proof.

Remark The fine structure for (v,3) DTSs when $v \equiv 2 \pmod{3}$ is more difficult. The difficulty is in determining (and proving) the necessary conditions. However, the author has found some results for this case.

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Appendix 1

Let $\mathcal{B} = \{\{1, 2, 3, 4, 5, 6\}, \{1, 7, 8, 9\}, \{2, 7, 10, 11\}, \{3, 8, 12, 13\}, \{4, 9, 14, 15\}, \{5, 10, 12, 14\}, \{6, 11, 13, 15\}\}$ and let \mathcal{B}_i be the blocks of Design i in this appendix, $i \neq 8$. Then $\mathcal{B} \cup \mathcal{B}_i$ yields a $(w, \{3, 4, 6\}, 1)$ PBD on $\{1, 2, 3, \ldots, w\}$, where $w \in \{15, 19, 21, 25, 27, 31, 33\}$. Let \mathcal{B}' be the blocks of Design 8 in this appendix and let $\mathcal{B}'' = \{\{1, 2, 3, 4, 5, 6\}, \{7, 8, 9, 10\}, \{11, 12, 13, 14\}, \{15, 16, 17, 18\}\}$. Then $\mathcal{B}' \cup \mathcal{B}''$ yields a $(18, \{3, 4, 6\}, 1)$ PBD on $\{1, 2, 3, \ldots, 18\}$.

No. v 15 2 19	{1,10,13} {3,7,14} {5,7,15} {1,10,17} {2,9,12} {3,10,15} {4,11,17}	{1,11,14} {3,9,11} {5,8,11} {1,11,14} {2,13,16}	{1,12,15} {3,10,15} {5,9,13} {1,12,15}	ples {2,8,15} {4,7,13} {6,7,12}	{2,9,12} {4,8,10}	{2,13,14} {4,11,12}
	{3,7,14} {5,7,15} {1,10,17} {2,9,12} {3,10,15}	{3,9,11} {5,8,11} {1,11,14} {2,13,16}	{3,10,15} {5,9,13}	{4,7,13}	{4,8,10}	{4,11,12}
2 19	{5,7,15} {1,10,17} {2,9,12} {3,10,15}	{5,8,11} {1,11,14} {2,13,16}	{5,9,13}			
2 19	{1,10,17} {2,9,12} {3,10,15}	{1,11,14} {2,13,16}		10,1,14		{6,9,10}
	{2,9,12} {3,10,15}	{2,13,16}	{1,12,13}	{1,13,19}	{6,8,14}	
	{3,10,15}		{2,15,18}	{1,13,19} {2,17,19}	{1,16,18}	{2,8,14}
			{3,14,19}		{3,7,18}	{3,9,17}
1 1 1		{3,11,16} {4,13,18}	{5,7,13}	{4,7,12}	{4,8,19}	{4,10,16}
	{5,16,19}	{6,7,17}	{6,8,10}	{5,8,11} {6,9,16}	{5,9,18}	{5,15,17}
	{7,14,16}	{7,15,19}	{8,15,16}		{6,12,19}	{6,14,18}
1 1 1	(10,18,19)	{11,12,18}	{12,16,17}	{8,17,18} {13,14,17}	{9,10,13}	{9,11,19}
	{1,10,16}	{1,11,12}	{1,13,20}	{1,14,17}	{1,15,18}	(1.10.01)
" "	{2,8,21}	{2,9,12}	{2,13,14}	{2,15,19}		{1,19,21}
1 1 1	{3,7,20}	{3,9,19}	{3,10,15}	{2,15,19} {3,11,21}	{2,16,17}	{2,18,20}
	{4,7,17}	{4,8,19}	{4,10,20}	{4,11,16}	{3,14,16}	{3,17,18}
1 1 1	{5,7,21}	{5,8,11}	{5,9,16}	{5,13,17}	{4,12,18}	{4,13,21}
	{6,7,16}	{6,8,18}	{6,9,17}	{6,10,19}	{5,15,20} {6,12,20}	{5,18,19}
	{7,12,15}	{7,13,19}	{7,14,18}	{8,10,17}		{6,14,21}
1 1 1	{9,10,13}	{9,11,18}	{9,20,21}	{10,18,21}	{8,14,20} {11,14,19}	{8,15,16} {11,17,20}
1 1 1	{12,16,21}	{12,17,19}	{13,16,18}	{15,17,21}	{16,19,20}	{11,17,20}
	{1,10,13}	{1,11,14}	{1,12,25}	{1,15,16}	{1,17,24}	{1,18,19}
	{1,20,21}	{1,22,23}	{2,8,19}	{2,9,12}	{2,13,23}	{2,14,24}
	{2,15,17}	{2,16,21}	{2,18,25}	{2,20,22}	{3,7,24}	{3,9,10}
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\[\begin{array}{c ccccccccccccccccccccccccccccccccccc							{12,22,30}	{12,25,32}
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\[\begin{array}{c ccccccccccccccccccccccccccccccccccc							{14,17,23}	{14,19,27}
\[\begin{array}{cccccccccccccccccccccccccccccccccccc	1				{14,26,30}	{15,16,27}	{15,18,21}	{15,20,32}
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{21,27,33} {21,31,32} {23,25,30}	1		{16,22,24}	{16,23,32}	{17,18,26}	{17,19,25}		{17,24,27}
			{18,22,31}	{18,25,33}		{19,22,29}	{19,28,32}	{20,24,28}
8 18 (1.7.14) (1.8.16) (1.9.11) (1.10.15) (1.12.17)								
-1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	8	18	{1,7,14}	{1,8,16}	{1,9,11}	{1,10,15}		{1,13,18}
								{2,11,15}
1 1 (-)								{3,12,15}
1 1 (-)	1							{4,11,16}
								{5,11,17}
							{6,10,11}	{6,12,18}
{6,14,15} {7,13,15} {8,11,18} {9,12,16}			[{6,14,15}	{7,13,15}	{8,11,18}	{9,12,16}		

Appendix 2

Let \mathcal{D}_i , $1 \le i \le 7$, be the blocks of Designs 1-7 in this appendix and let $\mathcal{D} = \{(1,3,4), (1,4,3), (2,1,4), (2,4,1), (3,2,4), (3,4,2), (4,1,3), (4,2,1), (4,3,2)\}$. Then $\mathcal{D} \cup \mathcal{D}_i \cup \mathcal{D}_i \cup \mathcal{D}_i$ yields a (w,3) DTS of type (0,3) on $\{1,2,3,\ldots,w\}$, where $w \in \{9,10,12,13,15,16,18\}$.

No.	เข	1		Trancit	ive triples		
1	9	(1,2,5)	(1,9,7)	(3,8,9)	(2,3,6)	(2,7,8)	(3,7,5)
	1	(7,4,9)	(4,5,6)	(4,8,7)	(5,2,9)	(5,1,8)	
		(6,9,4)	(6,7,1)	(7,6,2)	(6,8,3)	(9,6,5)	(8,5,4)
1		(9,8,2)	(5,7,3)	(8,1,6)	(0,0,0)	(8,0,3)	(9,3,1)
2	10	(1,2,5)	(1,6,7)	(8,9,3)	(2,3,6)	(2,7,8)	(0.10.c)
		(3,1,10)	(3,9,7)	(1,9,8)	(4,5,6)	(4,7,9)	(9,10,6)
		(5,10,8)	(5,9,2)	(5,7,3)	(6,10,4)	(8,6,2)	(4,8,10) (6,9,1)
[]		(6,3,8)	(7,10,1)	(8,7,4)	(9,5,4)	(10,7,2)	(10,3,5)
i i		(2,10,9)	(7,6,5)	(8,5,1)	(5,0,2)	(10,1,2)	(10,3,3)
3	12	(1,2,5)	(1,6,7)	(1,8,9)	(10,5,11)	(2,3,6)	(2,7,8)
ļ l		(2,9,10)	(2,11,12)	(3,1,12)	(3,7,5)	(3,8,10)	(3,9,11)
! !		(4,5,6)	(7,4,9)	(4,7,11)	(4,10,12)	(8,1,11)	(5,9,11)
		(5,10,3)	(11,5,4)	(6,5,12)	(11,6,8)	(6,1,10)	(3,9,2) $(10,4,8)$
l 1		(6,11,3)	(7,10,1)	(11,7,2)	(12,7,3)	(5,8,7)	(8,12,5)
		(9, 5, 1)	(9,8,3)	(9,6,4)	(10,7,6)	(8,6,2)	(11, 10, 9)
1		(12,6,9)	(12,10,2)	(12,11,1)	(9,7,12)	(12,8,4)	(11, 10, 3)
4	13	(1,2,5)	(1,6,7)	(1,11,9)	(1,13,10)	(12,13,5)	(2,3,6)
		(2,7,8)	(2,9,10)	(2,11,12)	(3,5,1)	(3,7,9)	(3,8,10)
		(3,11,13)	(4,5,6)	(4,7,10)	(4,8,11)	(4,9,12)	(5,2,13)
		(5,3,12)	(5,7,4)	(5,9,8)	(5,11,10)	(6,4,13)	(6,8,1)
1		(6,9,2)	(6,10,3)	(6,11,5)	(7,6,12)	(7,11,1)	(7,13,2)
		(8,7,3)	(8,12,2)	(13,8,4)	(9,7,5)	(9,11,3)	(9,13,1)
Į		(10,8,5)	(10,9,4)	(10, 12, 1)	(10, 13, 6)	(11,8,6)	(12,9,6)
		(12,10,7)	(12,11,4)	(13,11,7)	(13,12,3)	(10,11,2)	(1,12,8)
		(8,13,9)				· //-/	(-,,-)
5	15	(1,2,5)	(6,13,7)	(1,14,8)	(10,1,11)	(12,13,3)	(14,1,6)
l		(9,3,6)	(2,7,8)	(2,9,15)	(2,11,6)	(2,13,14)	(3,5,1)
ı	J	(5,3,7)	(3,8,10)	(3,13,11)	(8,3,14)	(4,5,6)	(2,3,12)
	í	(4,8,11)	(4,9,12)	(4,15,13)	(10,5,15)	(5,4,14)	(7,6,3)
		(5,8,12)	(8,5,9)	(5,10,13)	(6,12,15)	(6,8,1)	(6,9,2)
- 1	ı	(6,10,4)	(6,5,11)	(12,6,14)	(7,11,2)	(11,1,13)	(12,5,2)
	- 1	(7,13,4)	(7,15,5)	(8,13,2)	(14,3,15)	(8,15,4)	(13,9,8)
- 1	I	(9,13,1)	(14,9,4)	(1,15,9)	(10,8,6)	(10,3,9)	(12,1,7)
- 1		(9,10,7)	(11,8,7)	(11,12,9)	(11,15,3)	(15,10,2)	(1,10,12)
Ī	- 1	(12,11,4)	(13,15,6)	(7,9,14)	(14,13,5)	(15,14,11)	(15,12,8)
		(13, 12, 10)	(15,7,1)	(9,11,5)	(14,2,10)	(4,7,10)	(11,10,14)
		(14,7,12)					

No.	ย	Transitive triples							
6	16	(1,2,5)	(1,6,7)	(4,9,8)	(10,1,11)	(1,12,13)	(1,15,14)		
I		(2,12,6)	(2,16,7)	(10,2,9)	(8,11,1)	(13,2,14)	(16,12,3)		
1		(3,1,8)	(3,5,7)	(2,11,15)	(9,5,3)	(3,14,6)	(3,13,15)		
		(4,5,6)	(7,16,9)	(3,16,11)	(4,12,10)	(7,11,13)	(16,4,14)		
		(5,14,8)	(9,14,2)	(13,5,9)	(5,11,2)	(5,12,1)	(5,4,13)		
		(6,5,16)	(6,2,8)	(6,1,9)	(6,10,4)	(3,9,10)	(6,13,12)		
		(7,6,14)	(7,1,10)	(7,8,2)	(7,3,12)	(12,15,4)	(7,5,15)		
Į.	1	(8,10,6)	(12,8,7)	(8,4,16)	(8,15,13)	(8,14,5)	(15,12,5)		
1		(9,13,6)	(14,9,7)	(9,4,11)	(13,7,4)	(15,10,8)	(2,10,13)		
		(11,12,14)	(10,15,7)	(10, 16, 5)	(9,15,16)	(11,4,7)	(15,11,6)		
1		(11,16,8)	(12,11,9)	(12,16,2)	(14,13,11)	(14,10,3)	(10,14,12)		
		(14,16,1)	(15,2,3)	(15,9,1)	(16,6,15)	(16,13,10)	(14,4,15)		
		(13,1,16)	(13,8,3)	(8,9,12)	(6,11,3)	(11,5,10)	7 1 3		
7	18	(1,2,5)	(1,6,7)	(1,8,9)	(1,10,11)	(12,8,13)	(1,14,15)		
1		(16,17,2)	(2,3,6)	(5,2,7)	(9,2,10)	(2,11,12)	(2,13,14)		
1		(15,3,16)	(2,17,18)	(3,1,18)	(3,12,7)	(16,3,8)	(3,17,5)		
1		(3,9,14)	(18,3,13)	(1,17,16)	(4,5,6)	(4,7,9)	(4,8,11)		
1		(4,10,12)	(13,10,16)	(4,14,17)	(4,15,13)	(5,8,1)	(14,5,9)		
	ŀ	(10,5,3)	(17,11,13)	(5,12,15)	(5,13,17)	(5,14,16)	(6,5,18)		
		(6,2,8)	(6,9,1)	(6,10,4)	(6,11,3)	(12,16,1)	(6,14,13)		
		(15,17,12)	(7,10,1)	(7,11,2)	(17,7,3)	(13,7,4)	(7,14,12)		
1		(7,15,6)	(8,7,18)	(7,8,17)	(8,12,4)	(8,3,10)	(8,14,6)		
· ·	i	(8,15,5)	(8,2,16)	(9,12,17)	(9,13,6)	(12,14,3)	(15,9,4)		
	l	(9,7,16)	(17,9,8)	(10,9,18)	(10,13,2)	(10,14,7)	(10,15,8)		
	l	(16,5,10)	(10,17,6)	(3,15,11)	(14,11,8)	(11,15,7)	(11,16,6)		
	i .	(11,5,4)	(11,18,9)	(12,11,10)	(11,17,1)	(12,18,2)	(1,13,12)		
	1	(18,7,5)	(12,9,5)	(14,18,1)	(13,9,3)	(15,14,2)	(6,16,12) (6,17,15)		
1	l	(16,7,13)	(16,14,4)	(2,9,15)	(13,5,11)	(17,14,10)			
1	l	(18,12,6)	(13,18,8)	(18,11,14) (18,16,15)	(15,18,10)	(18,17,4)	(16,9,11)		
L	<u> </u>	(13,15,1)	(4,16,18)	(10,10,13)					