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Contents

ARTICLE

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ARTICLE

On Detecting and Enforcing the Non-Relational Constraints Associated to Dyadic Relations in *MatBase*

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ABSTRACT

MatBase is a prototype data and knowledge base management expert intelligent system based on the Relational, Entity-Relationship, and (Elementary) Mathematical Data Models. Dyadic relationships are quite common in data modeling. Besides their relational-type constraints, they often exhibit mathematical properties that are not covered by the Relational Data Model. This paper presents and discusses the *MatBase* algorithm that assists database designers in discovering all non-relational constraints associated to them, as well as its algorithm for enforcing them, thus providing a significantly higher degree of data quality.

1. Introduction

MatBase [10-13] is a prototype data and knowledge base management expert intelligent system based on the Relational (RDM) [1,3,6], the Entity-Relationship (E-RDM) [2,6,18], and the (Elementary) Mathematical ((E)MDM) [10,13] Data Models, as well as on Datalog [1,13], already successfully used for years by a couple of software developing companies, as well as in our University Database lectures and labs. Currently, there are two implementations of *MatBase*: one mainly for University labs developed in MS Access and one mainly for the IT industry developed in C# and MS SQL Server.

Any (conventional) database (db) scheme is a triple <*S, M, C*>, where *S* is a non-void finite collection of sets, *M* a finite non-void set of mappings defined on and taking values from sets in *S*, and *C* a similar one of constraints (i.e. closed first-order predicate calculus with equality formulas [17]) over the sets in *S* and mappings in *M*. Sets and mappings constitute the structure of dbs, while constraints, which are formalizing business rules, are meant to allow storing only plausible data into them.

In RDM, the sets of *S* are tables and views, the mappings of *M* are their columns, and the constraints of *C*

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are incorporated in the table schemes. Unfortunately, both RDM and E-RDM have only a handful of constraint types, which are not at all enough to guarantee data plausibility. Most of the RDM Management Systems (RDBMS) provide only 6 types of (relational) constraints, namely: domain (range), not-null, default value, key (uniqueness), foreign key (referential integrity), and check (tuple).

For example, using only these 6 types of constraints, even a very simple table (storing automatically generated id numbers in column *P_Id*, First and Last Names, Birth and Passed Away Dates, Sex, and parents of some people of interest, having foreign keys *Mother* and *Father*, both referencing *P_Id*, and not allowing persons to die before or more than 160 years after being born) like the one in Figure 1 might still store highly implausible data.

PERSONS (BDate* + 160years ≥ *PADate* ≥ *BDate)

P_Id	***FName***	***LName***	***BDate***	***Sex***	***Mother***	***Father***	***PADate***
auton	ASCII (64)	ASCII (64)	[1/1/1900, *today*]	{'F', 'M'}	in *P_Id*	in *P_Id*	[1/1/1900, *today*]
not-null	not-null	not-null	not-null	not-null			
1	John	Smith	1/1/2020	M	4	1	1/1/2020
2	Mary	Jane	1/1/1900	F	4	5	1/12/1999
3	Paul	Smith	1/1/2010	M	1	2	1/1/2012
4	Anne	Jane	1/1/2020	F	4	3	
5	Peter	Smith	1/1/1990	M	2	2	

Figure 1. A table with relationally valid, but highly implausible data

It is quite simple to check that data in this table does not violate any of its relational constraints (5 of domain type, 5 not-nulls, 1 key, 2 foreign keys, 1 check/tuple). However, this data is highly implausible, because, according to it:

(1) John Smith is his own father and has a mother born same day as him.

(2) Mary Jane has a mother born after she died, a father born 90 years after her birth, and is the father of her father.

(3) Paul Smith has a man (born after him) as mother and a woman (who died 20 years before his birth) as father.

(4) Anne Jane is her own mother and has a father who died 8 years before her birth.

(5) Peter Smith has a woman as both father and mother, was born 90 years after her birth, and is the father of his father.

In (E)MDM, in order to prevent storing such implausible data, the following 6 non-relational constraints should be added to the above 14 relational ones, in the scheme of this table:

(1) C_1: $(\forall x \in PERSONS)(Sex(Mother(x)) = \text{'F'})$ (i.e. only women may be mothers)

(2) C_2: $(\forall x \in PERSONS)(Sex(Father(x)) = \text{'M'})$ (i.e. only men may be fathers)

(3) C_3: *Mother* acyclic, C_4: *Father* acyclic (i.e. nobody may be her/his own mother/father, neither directly, nor indirectly)

(4) C_5: $(\forall x \in PERSONS)(BDate(x) \leq PADate(Mother(x)) \wedge BDate(x) + 5\text{years} \leq BDate(Mother(x)) \leq BDate(x) + 75\text{years})$ (i.e. no mother may give birth after her death, before being 5 years old, or after being 75 years old)

(5) C_6: $(\forall x \in PERSONS)(BDate(x) \leq PADate(Father(x)) + 10\text{month} \wedge BDate(x) + 9\text{years} \leq BDate(Father(x)) \leq BDate(x) + 100\text{years})$ (i.e. no father may have a child after 10 months from his death, before being 9 years old, or after being 100 years old)

As proved by this example (as well as many others, see, e.g. [6,7,13]), when a single business rule is not formalized by a corresponding constraint and/or that constraint is not enforced in the corresponding db scheme, implausible data may be stored in that db.

Just like for object sets and mappings between them, constraints can be discovered only by humans. However, computer science and math can assist in this process: e.g. the keys discovery assistance algorithms [6,8,13], the algorithm for assisting discovery of non-relational constraints associated to the E-RDM diagram cycles [11,13], the similar ones for endofunctions and object constraints [12,13], the constraint sets coherence and minimality ones [10,13], etc.

Currently, non-relational constraints are, unfortunately, not discovered by db architects, who are not even aware of their typology. Some of them are considered by some software architects, sometimes, but always in an ad-hoc manner. Most of them are ignored, so not enforced, reported then as bugs by customers, and enforced as software fixes, most of the times too late, after corresponding db instances are seriously polluted with implausible data.

This paper introduces and discusses first an algorithm for assisting discovery of non-relational constraints associated to dyadic relations, providing a valuable tool to db and software architects. By replacing in it dyadic relationships with tables and mappings with columns, one may successfully use it for corresponding RDM table schemes as well (corresponding table schemes should have a concatenated key made out of two not null foreign keys referencing a same other table).

This algorithm is embedded in *MatBase*, which is also automatically generating code for enforcing all non-

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relational constraint types provided by (E)MDM, thus significantly enhancing productivity and quality of db applications development. This paper also presents and discusses the algorithm for enforcing the constraints associated to dyadic relationships.

This first section presents an overview of the 73 (E) MDM constraint types, related work, and the paper outline.

1.1 (E)MDM Constraint Types

(E)MDM provides three constraint categories: set, mapping, and object [10,13].

The set category has two subcategories (and 16 types):

(1) general set (comprising five types: inclusion, set equality, disjointness, union, and direct sum) and

(2) dyadic relation (comprising eleven types: connectivity, reflexivity, irreflexivity, symmetry, asymmetry, transitivity, intransitivity, Euclideanity, inEuclideanity, acyclicity, equivalence).

The mapping category has five categories (and 56 types):

(1) General function (having six types: totality, nonprimeness, one-to-oneness, ontoness, bijectivity, and default value),

(2) Endofunction (having thirteen types: reflexivity, null-reflexivity, irreflexivity, symmetry, null-symmetry, asymmetry, idempotency, null-idempotency, anti-idempotency, equivalence, null-equivalence, acyclicity, canonical surjection),

(3) Function product (having three types: existence, nonexistence, and minimal one-to-oneness),

(4) Homogeneous binary function product (having eighteen types: connectivity, null-connectivity, reflexivity, null-reflexivity, null-identity, irreflexivity, symmetry, null-symmetry, asymmetry, transitivity, null-transitivity, intransitivity, Euclideanity, null-Euclideanity, inEuclideanity, acyclicity, equivalence, null-equivalence), and

(5) Function diagram (having sixteen types: commutativity, null-commutativity, anti-commutativity, generalized commutativity, local commutativity, local null-commutativity, local anti-commutativity, local symmetry, local null-symmetry, local asymmetry, local idempotency, local null-idempotency, local anti-idempotency, local equivalence, local null-equivalence, local acyclicity).

The object constraints are generalizing RDM tuple (check) constraints, being closed Horn clauses [17] (e.g. C_1, C_2, C_5, and C_6 above).

A *generalized commutativity* constraint is an object constrained associated to a function diagram (i.e. implying only sets and mappings from that diagram).

Please recall that dyadic relations are binary homogeneous ones (e.g. $PREREQUISITES \subseteq COURSES^2$), endofunctions (autofunctions, self-functions) have same domain and codomain (e.g. *Mother* : $PERSONS \rightarrow PERSONS$), and homogeneous binary function products (hbfp) are of the type $f \bullet g : D \rightarrow C^2$ (e.g. $EmbarkmentAirport \bullet DestinationAirport : BOARDING\_PASSES \rightarrow AIRPORTS^2$).

For the differences between mathematical relations and db relationships see [9]. In (E)MDM, dyadic relationships are denoted $R = (f \rightarrow T, g \rightarrow T)$, where f and g are R's roles (i.e. mathematically, the corresponding canonical Cartesian product projections).

For example, the dyadic relationship *PREREQUISITES* = (*Prerequisite* → *COURSES, Course* → *COURSES*) should always be acyclic: otherwise, no student might ever enroll in any of the courses involved in a cycle.

Any dyadic relationship has the following 5 relational constraints: both f and g are not null and foreign keys referencing table T, and $f \bullet g$ is a key.

Object constraints may be as well associated to dyadic relations (e.g. $(\forall x \in PREREQUISITES)(\forall y,z \in ENROLLMENTS)(Student(y) = Student(z) \wedge Course(y) = Prerequisite(x) \wedge Course(z) = Course(x) \Rightarrow EnrollDate(z) > CompletionDate(y))$, i.e. no student may enroll to a course before completion of all of its prerequisites) and to endofunctions [12,13].

A function is *total* if it does not take null values (i.e. it is totally defined or, equivalently, its codomain is disjoint from the NULLS distinguished set of null values) and is *nonprime* if it cannot be part of any key (i.e. not only not one-to-one, but not a member of any minimally one-to-one function product; e.g. *Height, Length, Width, Color,* etc.).

An endofunction or a hbfp that may take null values and has property P (e.g. reflexivity, symmetry, etc.) for all of its not null values is said to have property *null-P* (e.g. *ReplacementPart* : $PART\_TYPES \rightarrow PART\_TYPES$ is null-idempotent, because any replacement part type is replaced by itself, but there are part types that may not be replaced by other ones).

(E)MDM extended the RDM *existence* constraints $f \vdash\!\!\!- g$ ("whenever f takes not null values, g must take not null values as well") by allowing both f and/or g to be computed functions (e.g. $e\text{-}mail \vdash\!\!\!- City \bullet Address$, i.e. whenever the e-mail address of someone is known to the db, then both the city and the address within the city where he/she lives should also be known to the db).

A *nonexistence* constraint, denoted $\neg \vdash\!\!\!- f_1 \bullet \ldots \bullet f_n$, should be read "at most one of the $f_1, \ldots, f_n$ may be

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not null for any x" (e.g. $\neg \vdash\!\!\!\vdash TributaryTo \bullet Lake \bullet Sea \bullet Ocean \bullet LostInto : RIVERS \rightarrow RIVERS \times LAKES \times SEAS \times OCEANS \times GEOGRAPHIC\_UNITS$ formalizes the constraint "a river may empty in only one place, be it another river, a lake, a sea, an ocean, or another geographic unit type, e.g. a desert").

A function diagram made of mappings $f, g : D \rightarrow C$ (which may be atomic or composite functions) *anti-commutes* if $(\forall x \in D)(f(x) \neq g(x))$ (e.g. $(\forall x \in BOARDING\_PASSES)(EmbarkmentAirport(x) \neq DestinationAirport(x))$).

A function diagram has a *local property P* (e.g. symmetry, idempotency, etc.) in one of its sets if it is of the circular type [11,13] and the composite endofunction defined on and taking values from that set has the property *P* (e.g. the diagram made of the functions *Department* : *EMPLOYEES* → *DEPARTMENTS* and *Manager* : *DEPARTMENTS* → *EMPLOYEES* is locally idempotent in *EMPLOYEES*, because the composite endofunction *Manager* ° *Department* : *EMPLOYEES* → *EMPLOYEES* is idempotent, i.e. any manager works in the department that he/she manages).

1.2 Related Work

Theoretically, the (E)MDM is based on the semi-naïve theory of sets, relations, and functions [5], as well as on the first order logic [14].

Other mathematical data models are the categorial [17] and graph [4,16] ones.

Generally, there are very few db research results on non-relational constraints (e.g. [18]), except for the (E) MDM related ones ([10-13]).

MatBase algorithm for enforcing object constraints is presented in [12].

Dyadic relations were extensively studied within the realm of the set theory (e.g. [5]).

The most closely related approaches are based on business rules management (BRM) [15] and their corresponding implemented systems (BRMS) and process managers (BPM). From this perspective, *MatBase* is also a BRMS, but a formal, automatically code generating one.

A somewhat related approach as well is the logical constraint programming [19], aimed only at solving polynomial-complexity combinatoric problems (e.g. planning, scheduling, etc.).

1.3 Paper Outline

Section 2 concisely presents the *MatBase* graphical user interface (GUI) for managing relationships (which includes the subset of dyadic ones). Sections 3 is devoted to the *MatBase* algorithm for assisting discovery of dyadic relationship constraints. Section 4 presents the *MatBase* algorithm for enforcing the non-relational constraints associated to dyadic relationships. Section 5 discusses the complexity, optimality, and usefulness of these two algorithms. The paper ends with conclusions and references.

2. *MatBase* GUI for Relationships

Figure 2 shows the *RELATIONSHIPS* form that can be open from the *MatBase MetaCatalog / Scheme Updates / EMDM Scheme / Sets / Views* submenu. This form (together with its embedded subform) is the GUI for managing the db relationships' schemas.

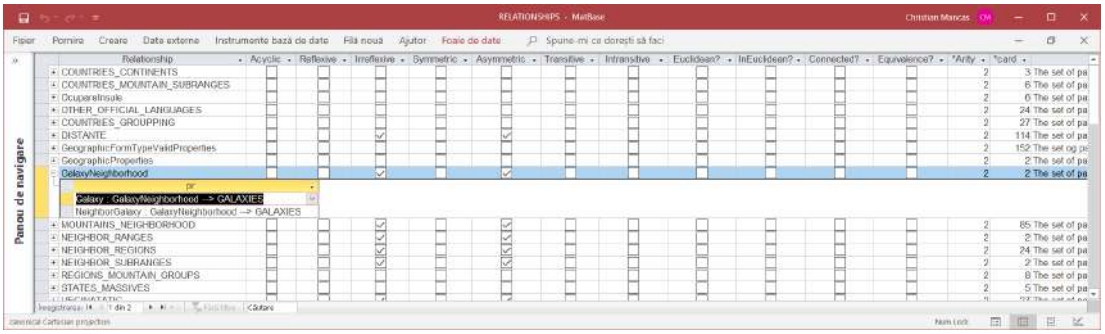

Figure 2. MatBase RELATIONSHIPS form and its subform

Besides the columns visible in this figure (with the computed **Arity* -displaying the number of roles- and **card* -showing the cardinality of the instances-), there are other ones as well: an optional *Description* (whose left end is visible in Figure 2), the required *Database* (to which relationships belong), a *System* flag (to distinguish between user and *MatBase* metacatalog relationships), etc.

Users may not only inspect the set of all relationships managed by the system, but also delete them (if they are not underlying sets for hierarchically higher order relationships), insert new relationships and/or modify existing ones.

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For example, the currently selected row in Figure 2 corresponds to the dyadic relationship *GalaxyNeighborhood* = (*Galaxy* → *GALAXIES*, *NeighborGalaxy* → *GALAXIES*) from the *Geography* db, which has been declared to be irreflexive (as no galaxy is its own neighbor) and asymmetric (as, whenever galaxy x is neighbor to galaxy y, it does not make sense to also store the fact that *y* is neighbor to *x*).

The embedded subform manages the roles (i.e. the canonical Cartesian projections) of the relationships.

The checkboxes from *Acyclic*? to *Equivalence*? are active only for the dyadic relationships. Whenever you uncheck one of them and then you confirm your request, *MatBase* either rejects it if it is a redundant one (e.g. if that relationship is acyclic, you cannot uncheck either asymmetry or irreflexivity, as both are implied by acyclicity) or is removing the automatically generated code for enforcing the corresponding constraint.

Whenever you check one of them and then you confirm your request, *MatBase* first checks whether the newly resulted constraint set is coherent [10,13] and rejects it if this is not the case (e.g. you cannot declare a relationship being both acyclic and symmetric); then, it checks whether the data instance of that relationship satisfies the desired constraint and rejects it if this is not the case (e.g. you cannot declare a relationship as being irreflexive as long as there is a pair of the type <*x, x*> in its data instance); finally, if everything is ok, *MatBase* accepts the new constraint and automatically generates the code for enforcing it; moreover, it also automatically remove the code for enforcing constraints that became redundant (e.g. if the relationship was irreflexive and becomes acyclic, irreflexivity enforcing code is removed) and checks all corresponding implied constraints.

Whenever you double-click on the row corresponding to a dyadic relationship and confirm your request, *MatBase* launches the algorithm presented in the next section, which assists users in the process of discovering all non-relational constraints associated with that relationship.

3. *MatBase* Algorithm for Assisting Discovery of Dyadic Relationship Constraints

Figures 3 and 4 present the Algorithm *ADDRC*, designed for assisting discovery of dyadic relationship constraints, which is implemented in both *MatBase* versions.

This Algorithm is optimally designed by incorporating the following mathematical results on dyadic relation properties [5,10,13]:

✓ acyclicity ⇒ asymmetry

✓ asymmetry ∨ intransitivity ∨ inEuclideanity ⇒ irreflexivity

✓ asymmetry ∧ transitivity ⇒ acyclicity

✓ reflexivity ∧ Euclideanity ⇒ symmetry ∧ transitivity

✓ symmetry ∧ Euclideanity ⇒ transitivity

✓ symmetry ∧ inEuclideanity ⇒ intransitivity

✓ symmetry ∧ transitivity ⇒ Euclideanity

✓ symmetry ∧ intransitivity ⇒ inEuclideanity

✓ irreflexivity ∧ transitivity ⇒ asymmetry

✓ symmetry ∧ intransitivity ∧ inEuclideanity ⇒ ¬connectivity

ALGORITHM *ADDRC.* Dyadic Relationship Constraints Discovery Assistance

Input: a db scheme *S* and one of its dyadic relationship *R*
Output: *S* augmented with the newly discovered constraints associated to *R* (if any)
Strategy:
if *R* is, could and should be asymmetric then *addCnstr*(*R*, "asymmetric") else
if *R* is, could and should be symmetric then *addCnstr*(*R*, "symmetric") end if;
if *R* is, could and should be irreflexive then *addCnstr*(*R*, "irreflexive") else
if *R* is, could and should be reflexive then *addCnstr*(*R*, "reflexive") end if;
if *R* is, could and should be acyclic then *addCnstr*(*R*, "acyclic") end if;
if *R* is, could and should be transitive then *addCnstr*(*R*, "transitive") else
if *R* is, could and should be intransitive then *addCnstr*(*R*, "intransitive") end if;
if *R* is, could and should be Euclidean then *addCnstr*(*R*, "Euclidean") else
if *R* is, could and should be inEuclidean then *addCnstr*(*R*, "inEuclidean") end if;
if *R* is, could and should be connected then *addCnstr*(*R*, "connected") end if;
End ALGORITHM *ADDRC*;

Figure 3. Algorithm ADDRC (Dyadic Relationship Constraints Discovery Assistance)

ALGORITHM *addCnstr(R, C).* Adds constraint *C* to dyadic relationship *R*'s scheme

Input: a dyadic relationship R of db scheme *S* and a constraint type *C*
Output: *S* augmented with C for R and corresponding redundant constraints (if any)
Strategy:
S = *S* ∪ {*R C*};
Add corresponding redundant constraints for *R* in *S*;
End ALGORITHM *addCnstr*;

Figure 4. Algorithm addCnstr

For any dyadic relationship *R*, "is *C*" means that its data instance satisfies constraint (i.e. mathematical property) *C*; "could be *C*" means that by adding constraint *C* to its scheme, its constraint set remains coherent (i.e. it does not contain any contradiction, see [10,13]) and that *C* is not already in the *R*'s scheme (not even as a redundant constraint); "should be *C*" is the question that *MatBase*

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asks its users in order to find out whether there is a business rule in the corresponding context stating that *R* must always satisfy constraint *C*.

Consequently, "*R* is, could and should be *C*" means that *MatBase* asks users "*R* should be *C*" only if both the syntactical condition "*R* could be *C*", as well as the semantical one "*R* is *C*" are true.

The order in which *ADDRC* considers the constraint types reflects our experience of more than 45 years in conceptual data modeling: most of the dyadic relationships are asymmetric (as their mathematical counterparts are symmetric), hence irreflexive too, then there are quite a lot of acyclic ones, with all other such constraint types being less usual. For example, in a *Geography* db [13], all 11 dyadic relationships are asymmetric (and hence irreflexive as well).

4. *MatBase* Algorithm for Enforcing the Dyadic Relationship Constraints

Figure 5 presents the Algorithm *AEDRC*, designed for enforcing the dyadic relationship constraints, which is implemented in both *MatBase* versions as well.

ALGORITHM *AEDRC.* Dyadic Relationship Constraints Enforcement

Input: - a db scheme *S*, its associated *RELATIONSHIPS* form instance, the user request (check / uncheck), the corresponding dyadic relationship $R = (f \rightarrow T, g \rightarrow T)$ non-relational constraint type *c* from its current row, and the implied by *c* set *I*, as well as the set *I'* of the constraints implied only by *c* and not desired anymore in *S*;
- *Cancel = False*;
Output: if *Cancel* **then** *S*
else if uncheck **then** $S = S - \{c\} - I'$ **else** $S = S \cup \{c\} \cup I$;
Strategy:
select user request
case uncheck:
if user does not confirm his/her delete request **then**
Cancel = True;
check *c*'s checkbox; // undo request
else if *c* is implied by some subset of constraints *C*' **then**
Cancel = True;
check *c*'s checkbox; // undo request
display "Constraint cannot be deleted as it is implied by C'!";
else
loop for all event-driven methods of the classes associated to R
delete line assigning to Cancel the value returned for c by the
corresponding constraint type enforcement Boolean function;
end loop;
$S = S - \{c\}$;
loop for all constraints c' in S that were implied only by *c*
if user wishes to keep c' **then** generate code needed to enforce c';
else $S = S - \{c'\}$;
uncheck *c*'s checkbox; // remove unwanted implied constraint
end if;
end loop;
end if;
case check:
Cancel = isCoherent(*c*);
if *Cancel* **then** uncheck c's checkbox; // undo request
display "Constraint rejected: constraint set would become incoherent!";
else *Cancel = isValid*(*c*);
if *Cancel* **then** uncheck c's checkbox; // undo request
display "Constraint cannot be enforced: current db instance violates it!";
else
loop for all event-driven methods of the classes associated to *R* (and generate all those that might be missing)
inject line assigning to *Cancel* the value returned for *c* by the corresponding
constraint type enforcement Boolean function;
end loop;
$S = S \cup \{c\} \cup I$;
loop for all constraints *c*' in *I*
check the checkbox corresponding to c'; // store that f also obeys c'
end loop;
end if;
end if;
end select;
End ALGORITHM AEDRC;

Figure 5. Algorithm AEDRC (Dyadic Relationship Constraints Enforcement)

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The Boolean functions *isCoherent* (checking that adding / removing a constraint satisfies or violates coherence) and *isValid* (checking whether the current db instance satisfies a given constraint), as well as many other useful functions for automatically enforcing constraints generated code, are provided by *MatBase* in its *Constraints* library [12,13].

5. Results and Discussion

5.1 Algorithms' Complexity and Optimality

It is very easy to check that both these algorithms are very fast, as they are never infinitely looping and their time complexities are $O(|C|)$ (i.e. linear in the average number of dyadic relationship fundamental constraints, generally between 0 and 3 [13]), for *ADDRC*, and $O(|I|)$ (i.e. linear in the average number of implied constraints by a non-relational dyadic relationship constraint, generally between 0 and 5 [13]), for *AEDRC*, respectively.

ADDRC is trivially not infinitely looping, as each dyadic relationship and corresponding constraint types are considered only once.

In the worse case (in which no non-relational constraint is initially asserted for the current dyadic relationship and none is discovered either), *ADDRC* is asking users all of the 10 possible questions. Coherence and minimality of the constraint sets are almost instantly checked, with only two table row reads [10,13]. Only checking whether the data instance of a dyadic relationship takes time proportional with its cardinal (i.e. the number of rows in the corresponding table). Consequently, it is preferable to assert all such non-relational constraints immediately after defining the relationship schemas, before allowing users to enter data for them.

Moreover, *ADDRC* is also optimal, as, using both math and our decades of conceptual data modeling experience, it asks db designers the minimum number possible of questions for any dyadic relationship.

ADDRC is implemented in the *DoubleClick* event associated to the *MatBase* form *RELATIONSHIPS*.

AEDRC is trivially not infinitely looping either, as any checkbox corresponding to a dyadic relationship constraint type is considered only once.

Moreover, *AEDRC* is optimal too, as

(1) it searches in every object-oriented class only within the event-driven methods and no such method is visited twice and

(2) its implementations merges for deletions both code injections and deletions in a same step, whereas checking of implied constraints by a newly added one is done in internal memory (and are saved in the db together with the one done by users in the current constraint checkbox, when the current row from *RELATIONSHIPS* is saved).

AEDRC is implemented in the *BeforeUpdate / Validating* for checkbox controls associated to the non-relational constraint types of the form *RELATIONSHIPS*.

5.2 Algorithms' Usefulness

The main utility of *ADDRC* is, of course, in the realms of data modeling and db constraints theory, whereas the one of *AEDRC* in the db and db software applications design and development ones: all constraints (business rules) that are governing the sub-universes modelled by dbs, be them relational or not, should be discovered and enforced in the corresponding dbs' schemas; otherwise, their instances might be implausible.

Dyadic relationships have sometimes associated non-relational constraints that may be much more easily discovered by using the assistance algorithm *ADDRC* presented in this paper.

Being transparent to users and automatically generating constraint enforcement code, *AEDRC* not only significantly enhances software architects and developers productivity, but also saves them lot of debugging effort and guarantees a very high quality standard.

6. Conclusion

In summary, we have designed, implemented, and successfully tested in both *MatBase* latest versions (for MS Access and C# and SQL Server) an algorithm for assisting discovery of all non-relational constraints associated to dyadic relationships, another one for enforcing such constraints through automatic code generation, analysed their complexities and optimality, as well as outlined their usefulness for data modelling, db constraints theory, db and db software application design and development practices.

Very many non-relational db constraint types are attached to dyadic relationships (dr). The first algorithm presented in this paper helps users to analyse each such dr exhaustively and intelligently, such that they may discover all non-relational constraints associated to them in the minimum possible time. Moreover, through automatic code generation for enforcing them, *MatBase* significantly increases both software development productivity and quality.

These algorithms are successfully used both in our lectures and labs on Advanced Databases (for the postgraduate students of the Mathematics and Computer Science Department of the Ovidius University, Constanta and the Computer Science Taught in English Department

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of the Bucharest Polytechnic University) and by two Romanian IT companies developing db software applications for many U.S. and European customers in the Fortune 100 ones.

In fact, *MatBase* is automatically generating code for enforcing non-relational constraints not only for dyadic relationships, but also for object constraints, endofunctions [12,13], the rest of the functions (including Cartesian product ones), as well as for sets [13], which makes it also a formal BRMS and adds (E)MDM to the panoply of tools expressing business rules.

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ARTICLE

Comprehensive Implementation of the Border Area Mountain Steppe Electronic Information and Developed Cities Electronic Information and Information equalization scheme G-10 million G or more

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ABSTRACT

Under the condition that the laser can not be used bare fiber and the existing satellite is limited by electric energy and weight, the innovative wired magnetic fiber [1] cable, rich IP channel magnetic fiber receiver [2] and transponderless reflector satellite [3] technology combine with the existing technology to make the magnetic fiber superior to the optical fiber and can be used bare; the magnetic fiber technology is an innovative product under the existing technical conditions of the downlink frequency segment, which can only be used as a linear transmission satellite at present, so that the frequency segment can be bent transmission and realize the new cable of the reflector satellite and the magnetic fiber port "antenna"; Magnetic fiber, magnetic fiber port "antenna" and reflector satellite interoperability, infinite number of channels IP the inverse As wireless transmission, radio satellite (including ground and indoor relay "antenna") can also be combined with optical fiber interoperability, so that the extremely rich number of channels IP realize wired wireless electronic information network, terminal equipment upgrade to magnetic fiber receiver, solve the problem of serious imbalance between electronic information in border area, mountain area, grassland and developed city and broadband narrow mobile equipment, magnetic fiber can also be integrated with power network of low-cost multi-power ecological network body.

1. Introduction

Prior to the 1960s, two-row cables and coaxial cables were widely used to transmit electromagnetic wave frequencies below 1 GHz for wired cable information transmission, while more than 1 GHz of electromagnetic wave frequencies could not be transmitted by wired cable information. Up to now, they can only be transmitted in a straight line such as satellite transmission with more than 1 G of downlink frequency. So far, GHz more than 1 GHz in the middle to the optical frequency segment of the cable can only be transmitted in a straight line so far, such as satellites G 1 Because the optical fiber is transmitted by laser as the carrier, the laser has serious harm to the characters. Only under the closed optical fiber, it is impossible to irradiate or use the laser naked.

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A magnetic fiber reflector satellite and a magnetic fiber receiver with no transponder were invented to solve the problem of transmitting information by wire between the optical frequency segment of the optical fiber GHz and the optical frequency segment of the optical fiber cable Cable a series of blank and so on, below share these results for your reference.

2. Issues Addressed by Existing Technologies

At present, the most advanced is optical fiber transmission electronic information technology. Transmission of high frequency electricity by coaxial cable.

Magnetic waves are out of use. Optical fiber technology solves the problem that the high frequency electromagnetic wave attenuation of coaxial cable transmission is very serious, thus forming the urban cable network broadband and mobile phone rapid development, such as urban radio, television, broadband, communications and other electronic information networks such as rapid development; while the border areas, mountain areas, grasslands and other electronic information networks such as radio, television, broadband, communications and other slow development, serious polarization social problems. Optical fiber technology is seriously limited by technology, such as optical fiber must use a laser, it is impossible to transmit information in the way of irradiation because it hurts people, only to transmit information in the way of wire, plus cost problems, such as not It can lay optical fiber everywhere in grassland, border area and mountain area, which results in the serious imbalance between the electronic information of border area, mountain area and grassland and the electronic information of developed cities. In this way, only innovative technology can solve this serious social problem. the following is an innovative optical fiber cable with an electromagnetic wave frequency of more than 1 GHz along the wire, a magnetic fiber receiver with a IP channel [2], and a reflector satellite technology without an electronic transponder.

3. Innovative Magnetic Fiber Technologies

3.1 Structure and Products of Magnetic Fiber

Composition: metal material, metal surface and pipe composition, metal surface surrounded by pipe to form magnetic fiber, such as metal pipes; local non-metallic pipes are also feasible, such as ceramic pipes. Such as organic pipe plating a layer of metal is also the composition of magnetic fiber products or direct metal tube to form magnetic fiber products.

Application: More than 1 GHz of electromagnetic wave frequency carries electronic information on the inner surface of the pipeline of wired magnetic fiber cable reflected from near to far transmission, so that the current more than 1 GHz of electromagnetic wave frequency in straight line wireless transmission to bend laid magnetic fiber cable wired transmission.

Requirements: the surface of the pipe is smooth; the bending degree of the inner surface of the pipe is similar to that of the fiber. figure 1 magnetic fiber, figure 1 is the metal surface ,2 is the path of electromagnetic wave reflection, and 3 is the circular hole, which is the entrance of the mounting antenna.

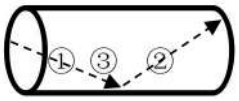

Figure 1. Magnetic fiber

3.2 Principles of Magnetic Fibers

Principle: reflection principle, it is recommended that the overall reflection is better.

3.3 Role of Magnetic Fibers

Similar to today, optical fiber itself is a straight line transmission into a curved transmission carrier, under the action of optical fiber transmission of light in a wired way to achieve today's optical fiber network change development. So far, the electromagnetic wave frequency segment over 1 GHz has been transmitted in a straight line wirelessly. The magnetic fiber technology has been invented, that is, the magnetic fiber is formed into a pipe with a metal surface. The electromagnetic wave frequency segment over 1 GHz is transmitted in a straight line to a curved transmission on the inner surface of the pipe. According to, under the action of the magnetic fiber, laying the bending propagation in any direction way.

3.4 Examples of Magnetic Fibers

3.4.1 Physical Objects

Such as coating a layer of metal on the inner surface of an organic pipe is also a magnetic fiber product or a direct metal tube constitutes a magnetic fiber product, see in detail "electromagnetic wave information and electricity transmitted more than 1 GHz by magnetic fiber technology"[4] or apply for patent no .201510237920 X "bending electromagnetic wave fiber tube to transmit high frequency electromagnetic wave information"[5], etc., as shown in figure 2 multi-satellite multi-reflector broadband

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power system. For example, in the magnetic fiber to solve the "study of China's urban and rural balanced development of radio, film and television information network master plan (top)(bottom)"[6] limitations.

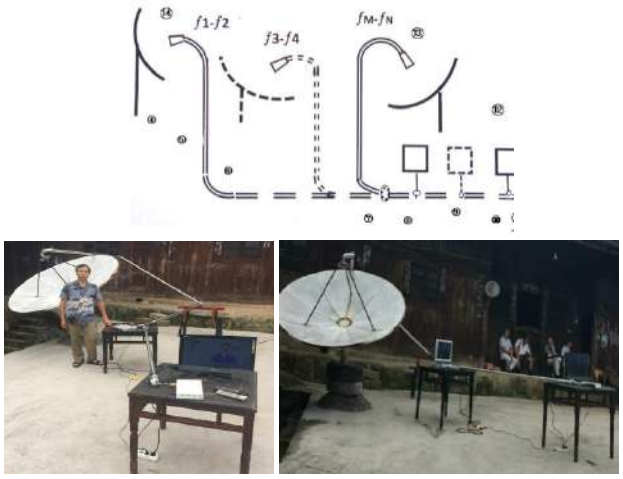

Figure 2. Multi-satellite Multi-reflective Surface Broadband Power System (left schematic, right physical)

3.4.2 Magnetic Fiber Technology is Multifunctional

Magnetic fiber technology can solve the problem of multi-satellite multi-reflector system engineering and high-frequency electromagnetic wave broadband transmission, and can also be integrated with power system.

A number of satellite reflectors are used to increase the flow of magnetic fibers, frequency, frequency segments, number of channels and information, as shown in *f*1-2, *f*3-4, *f*M-N. figure 2 This equipment, especially in the mountains, desert areas, areas of the very border areas, such as a series of rooms used by users or scattered individual use, greatly reduce costs. See Figure 2,(Figure 2*f*1-2, *f*3-4, *f*M-N the source of electromagnetic wave information in the high-frequency segment of a satellite with different downlink frequencies, reflected by the reflector), for more than GHz 1 transmission using magnetic fiber technology Electromagnetic Information and Electricity.

Without any technical improvements under the existing technical conditions, such as transmitter and satellite equipment, such as the implementation of different satellite downlink frequency transmission of different radio and television programs, it is easy to solve the problem of increasing magnetic fiber flux, frequency value, frequency segment value, number of channels and information, the receiver can use magnetic fiber technology to transmit, the implementation of border area, mountain area, grassland radio and television county-level media fusion, combined with asymmetric broadband, communications and other electronic information network media broadband fusion, see similar reference to the above "Research satellite and ground radio and television information comprehensive broadband program"[7] or power line and fiber integration to achieve access One step to implement low-cost, large-capacity, high-speed implementation of electronic information transmission balance, comprehensive reality of electronic information sharing on the ground ,"better guide the masses, serve the masses", but also make the following innovations.

4. Innovative Magnetic Fiber Receiver Technology

4.1 Magnetic Fiber Receiver

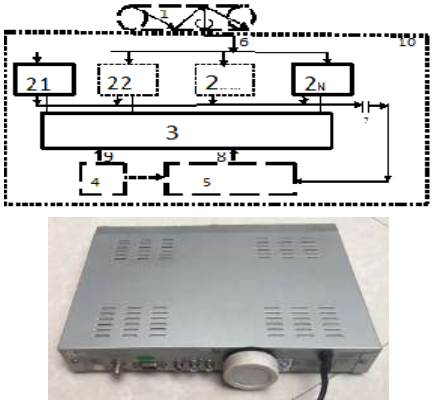

Figure 3. Schematic diagram of magnetic fiber receiver (left schematic, right physical)

Magnetic fiber receivers include: magnetic fiber over 10 G-million G of long and wideband magnetic fiber receivers including computer mainframe, mobile phones, routers, satellite receiver high-frequency head products)[8]

The structure of the magnetic fiber receiver is:

The existing devices such as mobile phones, computer hosts, routers, satellite receivers, high frequency heads, etc. are collectively referred to as electromagnetic wave receivers as shown in Figure 4 and 5, adding innovative technologies such as N LNB (2 N) and circuit boards of switch board 3 together to form an innovative device for receiving information, as shown in Figure 2(natural number),(circuit boards in Figure 3 are equivalent to a LNB (2 N) group of bus control circuit systems). N LNB (2 N) can be connected in parallel, series, series-parallel cooperative receiver part. the 2 N in figure 3 is a diagram of parallel, series or series-parallel mixing. The device is called a magnetic fiber receiver, where the magnetic fiber receiver mainly refers to the direct reception of more than 1 G of high frequency conversion equipment, such as figure 3 10 for the overall magnetic

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fiber receiver unidirectional input fiber receiver, as shown in the arrow direction in figure 3, the same realization of receiving and transmitting bidirectional information equipment, such as this device has the function of mobile phone, thus forming a new mobile phone. To make the description easy to understand, it is equivalent to an innovative device that directly integrates ground-satellite receiver equipment with existing technology, such as N satellite receiving high-frequency head LNB, so that the coaxial cable part in the middle is eliminated and becomes a magnetic fiber receiver. Surface, direct use of high-frequency electromagnetic wave information, is also mobile magnetic fiber receiver only magnetic fiber receiver antenna need to be improved (slightly).

4.2 The Principle of Extremely Rich Capacity for Magnetic Fiber and Magnetic Fiber Receivers

Innovative technology has been developed for magnetic fiber and magnetic fiber receivers. Magnetic fiber technology is wired transmission of more than 1 GHz of electromagnetic wave electronic information technology, this equipment is called magnetic fiber. The frequency of high frequency segments transmitted by magnetic fibers more than one GHz has a large number of channels, that is, the frequency IP address can be of the existing technology to calculate the large number of channels, the frequency IP address can be implemented as coding to solve the specific selection of channels, thus forming the channel IP address. A IP address with broadband, can reach hundreds of billions of IP address order of magnitude, can be compared with optical fiber, although each has its own advantages and disadvantages, but in electronic information popularization, optical fiber technology has not been better than magnetic fiber technology. The following is a brief discussion of the advantages and disadvantages of magnetic fiber technology and optical fiber technology.

5. Analysis of Innovative Technologies

5.1 Discuss the Advantages and Disadvantages of Magnetic Fiber Technology and Optical Fiber Technology

(1)fiber technology and magnetic fiber technology advantages: both have rich broadband IP address, the same speed of propagation.

(2)fiber technology shortcomings: optical fiber through the intermediate medium entity obstacles, optical fiber is the use of laser transmission, laser exposure damage to people and other particularly serious, can not be used naked, so at present, the main way to seal the transmission of information by wire, it is impossible to transmit information by irradiation, this is the nature of the city's electronic information developed. Because it is impossible to use it by cable, the electronic information of border area, mountain area and grassland is unbalanced with the electronic information of developed city.

(3)The advantages of magnetic fiber technology: magnetic fiber is to use more than 1 G of high-frequency electromagnetic wave transmission, solve the problem of high-frequency electromagnetic wave transmission of more than 1 G before more than 1 G, high-frequency electromagnetic wave damage to people and so on is not particularly serious, now realized: this section of electromagnetic wave can be wired, wireless transmission of high-frequency electromagnetic more than 1 G. As has been demonstrated in today's vast array of real-world uses of the 14 G downlink frequency of live satellites for decades. Existing wired and wireless modes are utilized as shown in Figure 2 and Figure 5 below and Figure 6 as fixed magnetic fiber receivers;

(4)"Antenna"

Or the high frequency electromagnetic wave that emits more than 1 G in front of the magnetic fiber port, that is, the magnetic fiber port "antenna", realizes the wireless receiving mode such as indoor and outdoor areas to implement the magnetic fiber port "antenna", and facilitates the use of mobile receivers such as 50 G broadband mobile phones, such as figure 2 above is not the satellite downlink frequency, but the implementation of the magnetic fiber port emitted more than 1 G of high frequency electromagnetic wave solution (limited space, specific technology, see another article, the same below). (Note: Self-installed magnetic fiber receivers, etc. can not produce standard objects due to their limited funds and no functional rights, please understand that the physical objects are simple); if the antenna of the magnetic fiber receiver is further improved, the migration will be formed Mobile receiver (limited space, technical details, see another article, the same below).

(5) Magnetic fiber technology can directly re-equip a reflector satellite, that is, the reflector satellite does not want electronic components such as transponders on satellites of the existing technology, and the satellite technology to solve the existing technology seriously limits the number of channels (or broadband bandwidth) and power, etc. Direct use of convex reflector and support to form a satellite, called reflector satellite (limited space, specific technology, see another article). A high-frequency electromagnetic wave G above the ground is directly reflected from the reflector directly by diffuse reflection, and scattered on the ground as a downlink frequency. The

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balance between information and electronic information in developed cities. This technology, optical fiber technology is absolutely impossible to use.

(6) Magnetic fiber lightning protection technology please refer to "Village Tong" lightning protection high-frequency head technology [9], "use magnetic fiber technology to transmit more than 1 GHz of electromagnetic wave information and electricity" [4] and "an electronic product lightning protection device "[10] and so on.

5.2 Technical Conclusions of Magnetic Fibers

(1) With regard to the current technical requirements, A, direct use of magnetic fiber technology and magnetic fiber receiver technology, direct use of multiple satellites to transmit a large number of continuous transmission of high-frequency electromagnetic waves of more than one G of downlink frequency, that is, different satellite frequency segments, to transmit electronic information to the ground receiving system; also can use magnetic fiber along the transmission and magnetic fiber port ejection transmission, both directly installed magnetic fiber receiver scheme.

(2) Implementation of reflector satellites, magnetic fiber technology and magnetic fiber receiver technology directly with reflector satellites constitute a system, transmission of high-frequency electromagnetic waves of more than one G down frequency of different satellites at different frequency segments of multiple satellites into a reflector satellite, constitute a rich number of channels IP address wireless system, transmission of electronic information to the ground receiving system; also can use magnetic fiber along the transmission and magnetic fiber port transmission directly installed magnetic fiber receiver scheme, forming wired wireless free choice symmetrical network system and asymmetric network system.

(3) The combination of optical fiber and magnetic fiber, using the existing laid optical fiber network, in the existing terminal technology, the photoelectric conversion system such as the magnetic fiber port "antenna" is directly implemented, and the local area is directly realized between the magnetic fiber port and the magnetic fiber receiver, which is called the mobile receiver system network, the fixed receiver system and the wired receiver system network along the line with magnetic fiber as wired electronic information.

(4) Based on the integration of three networks and power lines, the effective electronic information network (EIN) and power network (EIN) are.

6. Implementation of the Electronic Information Balance Programme for Border Areas, Mountain Areas, Grasslands and Developed Cities

Figure 5. Preliminary physical drawing of magnetic fiber and magnetic fiber receivers received

A large number of continuously transmitted high-frequency electromagnetic waves of more than one G to transmit electronic information to the ground, or a reflector satellite system, are emitted by the magnetic fiber port irradiation (indoor and outdoor installation) or the existing satellite downlink frequency, which is received directly by a magnetic fiber receiver. Reference can be made to the physical actual product receiving diagram of the multi-satellite multi-reflector broadband power system in Figure 2, Figure 5, or to the installation of the magnetic fiber receiver along the magnetic fiber line, as shown in Figure 3. It is impossible to compare and solve technical problems with optical fiber technology. It is also impossible for optical fiber technology to balance the electronic information of border areas, mountain areas and grasslands with that of developed cities. The realization of social problems in backward grasslands and developed cities. If very low-income adopt the one-way reception of the Comprehensive Broadband Programme for Researching Radio and Television Information on Satellites and the Ground (such as the practical analogy of today's massive APP). With the support of the revision of national laws and regulations, adapting to the application of the new technology, we can realize the technical re-division of the four networks in one and the high frequency electromagnetic band. better guide the masses and serve the masses.

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ARTICLE

TEC Colling Shortwave Infrared 320×256 Focal Plane Detector

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Shortwave focal plane detector
Thermo electric cooler
Infrared

ABSTRACT

The short-wave HgCdTe thin film material was grown by liquid phase epitaxy on CdTe substrate, Adopt n on p injection bonding and function and flip-flop mixing process, With a low noise readout circuit, sealed with a high airtightness cellular-metal shell, Using a four-stage Thermo Electric Cooler (TEC),320×256 Short Wave Infrared Focal Plane Cooling Detecto r available to operate at near room temperature (210K). Its main photoelectric performance are signal-to-noise ratio greater than 400, non-uniformity equivalent to 4.69%,operability equivalent to 99.76%,frame rate equivalent to 115Hz,component weight less than 150grams.

1. Introduction

Shortwave infrared imaging can adapt to the need of night vision and obtain clear imaging. Shortwave infrared imager can be used as a new generation of night vision equipment. It can be widely used in the sea, land and air, such as tank, vehicle, aircraft, ship and other night driving observation equipment, battlefield front surveillance equipment, single soldier helmet, gun-eye night vision detection equipment [1-3]. In addition, it can also be used as a light weapon day and night sight, motor platform night auxiliary driver, etc. Short-wave infrared imaging makes up for the deficiency of mid- and long-wave infrared night vision, fills the blank of short-wave infrared atmospheric window, and has unique advantages in many fields [4].

Since short-wave infrared detectors can work at near room temperature (≥200 K), low-cost and simple-structured thermo electric cooler can be used instead of expensive and complex Stirling coolers or throttling coolers, which have great advantages in the cost, weight and reliability of detector components and have wide application prospects [5].

2. Design and Implementation of Short-wave Mercury Cadmium Telluride 320×256 Focal Planar Detector

2.1 Structural Design of 320×256 Focal Plane Detector Assemblies for Mercury Cadmium Telluride in Short Waves

Shortwave 320×256 cadmium telluride mercury focal plane detector assembly using planar p-n junction

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structure, Based on zinc cadmium telluride (CdZnTe) substrate, Using liquid phase epitaxy (LPE) technology to grow shortwave HgCdTe (HgCdTe) films, Through surface treatment, surface passivation, ion implantation, To form focal plane arrays, Connected to the CMOS process readout circuit by planar flip-flop interconnection, Form a hybrid focal plane detector chip, Detector assemblies are cooled by a four-stage thermo electric cooler (TEC), sealed with a high airtightness cellular-metal shell.

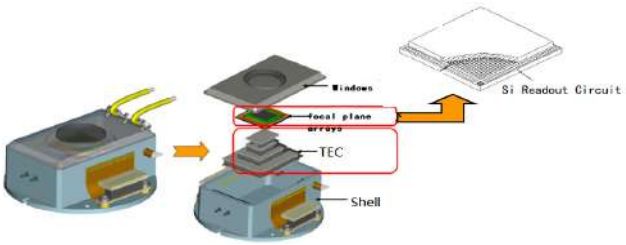

Figure 1. Composition of the detector assembly

How the shortwave 320×256 infrared detector module works: the infrared radiation of the target object converges to the photovoltaic diode array through the optical system. the focal plane array topology diagram is shown in figure 2. the photovoltaic diode converts the absorbed photons into photoelectric signals. the integrated capacitance of the corresponding pixel of the readout circuit is charged in the integral time and converted to voltage signal output after transfer and amplification. Through optical scanning, the signal processing circuit of the system encodes, modifies and displays the infrared information per element, and then forms the infrared thermal image of the target band.

2.2 Process Realization of Short-wave HgCdTe Thin Film Material and Focal Plane Detector Chip

In the study of short-wave HgCdTe film growth, the process route of raw material purification and high stability liquid phase epitaxial growth was designed, the high quality liquid phase epitaxial growth of HgCdTe film and the annealing technology of substrate material were studied.

The detector chip process was designed. a short wave 320×256 infrared detector chip with high uniformity was prepared by material surface treatment, bonding technology, surface passivation and penetration enhancement technology, ohmic contact of short wave materials, reactive etching research, molding process research, interconnection technology and other key technologies, as shown in figure 3.

Figure 2 Image element array topology diagram

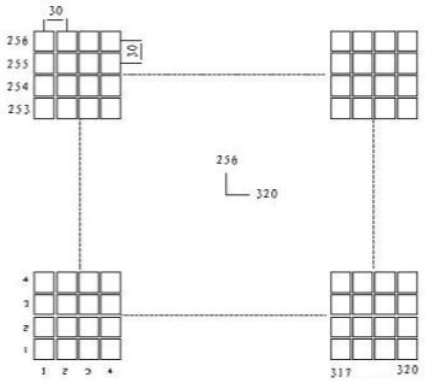

Figure 2. 320×256 focal plane array topology

Figure 3. Physical photograph of HgCdTe shortwave 320×256 focal plane chip

2.3 Design of Readout Circuit

The matching degree between the input level of the readout circuit and the characteristics of the detector unit determines the signal injection efficiency after the interconnection between the two, which affects the performance of the focal plane detector. The short-wave CdTe detector has high impedance and small photocurrent, and the optimal design of the input stage of the readout circuit will be the key to the development of the readout circuit. Design of readout circuit is based on submicron silicon CMOS technology. The readout circuit enables FPA to integrate (CTIA), store, line strobe, and sample-hold signals from photovoltaic diodes, using integration while read (IWR) mode. The design of the readout circuit adapts to the requirements of snapshot operation, and the integral time is programmable. The overall structure of the detector readout circuit is shown in figure 4.

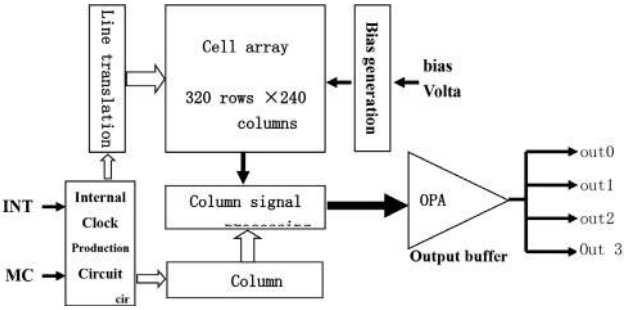

Figure 4. General structure of readout circuit

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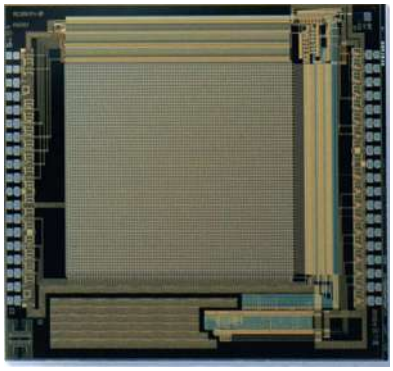

Figure 5. Physical photograph of 320×256 readout circuits of HgCdTe in short wave

2.4 Coolers

In this study, a four-stage thermo electric cooler was used as a refrigeration source for the short-wave focal plane detector to make the detector work around 200 K.Design and Development of Special Type Four-Stage Thermo Electric Cooler[6].In order to meet the demand of high current operation of the cooler, the technical size, logarithm and layout structure of the grain column are designed. The thermo electric cooler adopts four-stage structure, and the column material adopts Sb Bi-Te alloy semiconductor crystal. Each layer is connected by ceramic sheet. The first stage is 128 columns, the second is 52 columns, the third is 22 columns, and the fourth is 10 columns. Because of the small size (length and width size less than, height size less than), light weight, high reliability and so on. The volume and weight of the whole focal plane detector assembly can be effectively reduced. It provides great convenience for the design of the whole machine. Because of the high reliability of sthermo electric cooler, the reliability and service life of the whole detector assembly can be greatly improved, and the cost and price of the detector assembly can be greatly reduced because of the use of low cost thermo electric cooler instead of the expensive Stirling refrigerator.

2.5 High Airtightness Ceramic-metal Shell Structure Package

The principle of generality, small volume, light weight and high reliability are fully considered in the package structure. the shell components are all metal structure, integrated with thermo electric cooler, and side lead structure. the shell pin design must meet the requirements of detector chip signal drive and readout, and have good electromagnetic shielding ability.Packaging all parts using strictly controlled surface treatment process to ensure vacuum life and reliability.

The low temperature solder is selected according to the characteristics of the highest energy temperature of the TEC refrigerator, and the process of rapid cooling from the welding temperature is realized by using the accurate temperature control welding equipment to ensure that the TEC is not damaged. And meet the technical requirements of welding parallelism and position.

The metal-encapsulated window uses sapphires to ensure transmission 1μm -2.5μm infrared bands [7]. The suction agent is arranged in the package, which ensures that the device can activate the vacuum by charging the suction agent in the later stage, thus prolonging the service life of the detector.

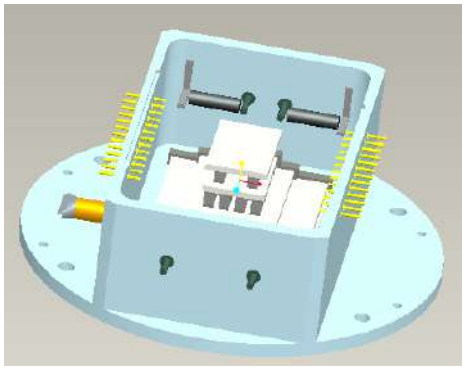

Figure 6. Internal structure of detector package

3. Component Performance and Environmental Testing

The photoelectric performance of the TEC cooling shortwave infrared 320×256 focal plane detector is tested. The main technical specifications are as follows: working temperature 210 K, signal-to-noise ratio >400, non-uniformity 4.69, operability 99.76%, frame frequency 115 Hz, component weight less than 150 grams.

The environmental adaptability of this component is studied. The contents of environmental test include high temperature storage, low temperature storage, high temperature impact, low temperature impact, high temperature work, low temperature work, mechanical impact and impact. After the environmental test, the component performance did not change obviously.At the same time, the performance of components stored in conventional environment for one year is re-tested, and the performance is not declining.

4. Conclusion

A shortwave infrared 320×256 focal plane detector with low price and simple structure is used to replace the expensive Stirling refrigerator or throttling refrigerator with

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complex structure.

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ARTICLE

Exploratory Study on the Simulated Police Force Allocation of Shopping Mall Emergency Based on AnyLogic Platform

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ABSTRACT

Due to the rapid development of society, public places, especially large shopping malls, are relatively frequent places for emergencies. Such emergencies not only seriously affect public security and property, but also bring great psychological pressure to citizens. Therefore, this study is of great significance for the exploration and study of public place emergencies.The research object of this study is the public shopping mall. Based on the AnyLogic simulation platform and guided by the relevant principles of social force model, this study utilize the pedestrian storehouse in the platform as the core module to build the simulation environment, and attempts to simulate the police force restraining effect on the overall event and the perpetrators after the occur of emergent incident under different police force allocations. In order to ensure the accuracy of the experimental data, the research team conducted field survey to estimate the average flow of people and the general data of the security personnel in shopping malls, also estimated the rest rain and capture time after repeated experiments.The results indicate that increasing additional police force outside the shopping malls and pre-organizing reasonable patrol routes can obviously facilitate police officers to restrain perpetrators. Meanwhile, it is also clear that the AnyLogic platform can effectively simulate pedestrian movement and interaction behaviour in emergencies.

1. Introduction

In recent years, with the rapid development of computer technology, various modeling methods and simulation theory are progressing increasingly. Simulation gradually contributes to the social development in a more convenient manner, affecting our lifestyle in various aspects. As a complete simulation software supporting multiple joint modeling methods, AnyLogic platform attracts an increasing number of researchers with its powerful performance and well-designed modeling tools [1], AnyLogic not only has an intuitive and friendly graphical interface, but also is fully compatible with Java. In addition, AnyLogic is competent for simulation work in most cases with an open and easy-to-use programming method.AnyLogic simulation modeling has produced a great number of successful cases in many fields. Dan Zheng and others utilized AnyLogic to simulate the complex evacuation behavior effectively [1]. Shengtao Ma et al conducted simulation research on traffic congestion based on AnyLogic [2].Zhenwu Zhao and his team studied the simulation and optimization of airport passenger

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security inspection process based on the AnyLogic platform [3]. Wenke Zhou and others utilized AnyLogic software to illustrate the speed changing process and the route selection results of crowd under the fire development [4].With the emergence of new modeling methods and technologies, as well as the rapid growth of computer performance, it is reasonable to predict that simulation modeling technology based on AnyLogic will be applied to more extensive fields.

To sum up, it can be seen that there are limited number of police simulation studies based on AnyLogic platform. This study aims to apply this method to police work though AnyLogic simulation software. In specific, utilize simple simulation model construction, set up a certain level of police force and the best patrol route, then conduct experiment with different police force allocations as the comparison scheme, observe how the time required to restrain perpetrators changes with the number of police forces after the incident, so as to explore the issue of police force allocation.It is hoped that this study will facilitate police officers to deal with similar emergencies and formulate prevention and control plans.

2. Principle of Social Force Model

Human simulation mainly relies on pedestrian storehouse and agent, and reflects the change process of pedestrian by building flow chart and logic. The main focus of this study is not the crowd evacuation behavior, therefore the logic diagram of shopping mall customer agent will be briefly illustrated as follow:

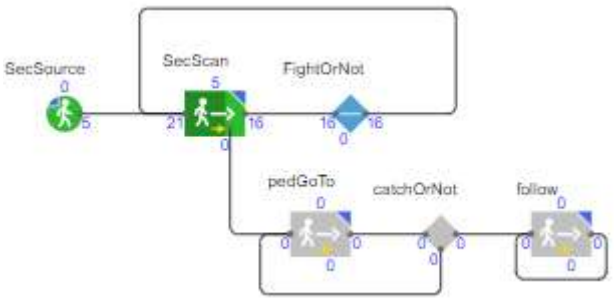

Figure 1. Pedestrian flow

The core of pedestrian storehouse is the social force model proposed by Helbing and Molna [5-8], which can reflect the force between pedestrians and between pedestrians and the outside world, and can also simulate the phenomenon of pedestrian self-organization and escape behavior [9]. Its dynamic equation is:

$$m_a \frac{d\vec{\omega}_a}{dt} = \vec{F}_a(t) + \xi \qquad (1)$$

$$\vec{F}_a(t) = \vec{F}_a^0\left(\vec{v}_a, v_a^0\vec{e}_a\right) + \sum_\beta \vec{F}_{a\beta}\left(\vec{e}_a, \vec{r}_a - \vec{r}_\beta\right) + \sum_B \vec{F}_{aB}\left(\vec{e}_a, \vec{r}_a - \vec{r}_B\right) + \sum_i \vec{F}_{ai}\left(\vec{e}_a, \vec{r}_a - \vec{r}_i, t\right) \qquad (2)$$

In the first formula, m_α is the pedestrian mass; ω_α is the expected speed of pedestrians in the current environment; in the second formula, $\vec{F}_a$ (t) is the resultant force exerted on the personnel in the model. The small term in the second formula represents the driving force, the interaction between pedestrians, the interaction between pedestrians as well as the surrounding barrier boundary, and the resultant force of attraction; and ξ is a random variable.As a comparatively accurate pedestrian dynamic model, social force model can effectively reflect pedestrian flow and pedestrian interaction behaviors, and has been applied to many pedestrian simulation studies.

3. Model Parameter Setting

Due to the software design and technical reasons, the complex large-scale shopping mall is abstracted into a simple structure model to simulate the shopping mall emergent incident, and simple variables will be utilized for analysis and research. The simulation interface of the shopping mall is shown below, among which the blue individual is the police. It is clear from the graph that police force is set up in the shopping mall, both the number of police and the patrol route can be adjusted dynamically.When the emergent incident happened, the alarm of shopping mall will sound and the crowd will begin to escape and evacuate. The nearby police and the security personnel of the shopping mall will quickly rush to the incident spot, hold and arrest the perpetrator.

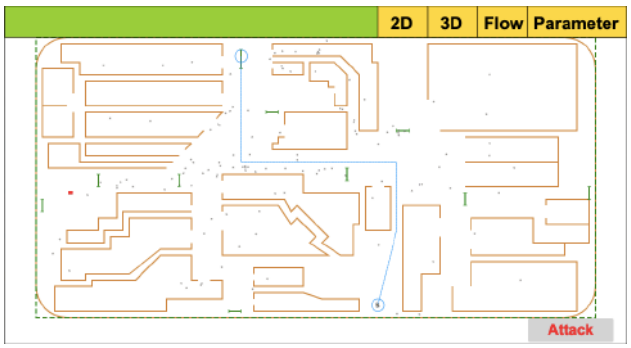

Figure 2. Simulation animation display

This study sets up three agents,including pedestrian, perpetrator and police, and the corresponding functions compiled in the software are applied to define the agents' delayed behaviors in shopping malls, such as dining and

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shopping. The behavior state of the agents is defined by the state diagram in the pedestrian module and given with correlation functions.

The status of pedestrians is shown in Figure 3, which includes three states: In the shop, Out of the shop and dead. The Ped Wait module is used to describe the pedestrian behavior in the mall, and Uniform (10,20) indicates that the agent's residence time in the area is about 10-20 minutes; send ("inshop", ped) and send ("outshop", ped) are used to describe the behavior of agents entering and leaving the area, and the initial speed is set as 2m / s.

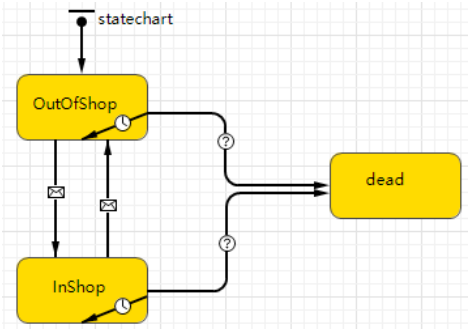

Figure 3. Pedestrian Status

The status of the perpetrator is shown in Figure 4, which includes five states: waiting, scanning, chasing, killing and caught. In terms of perpetrators, it is necessary to set detailed state commands in the agent state to define their specific behavior states. The command to find the target state (scanning) is as follows:

```
this.setSpeed(normalSpeed);
Main.X_killer = this.getX();
Main.Y_killer = this.getY();
```

The order of chasing a target state (chasing) is as follows:

```
this.setSpeed(chasingSpeed);
Main.X_killer = this.getX();
Main.Y_killer = this.getY();
```

The command to kill the target status (killing) is as follows:

```
stop();
victim.statechart.receiveMessage("killed");
victim.killOrNot = 1;
Main.X_killer = this.getX();
Main.Y_killer = this.getY();
```

The final status of the arrest order(caught) is:

```
getEngine().finish();
```

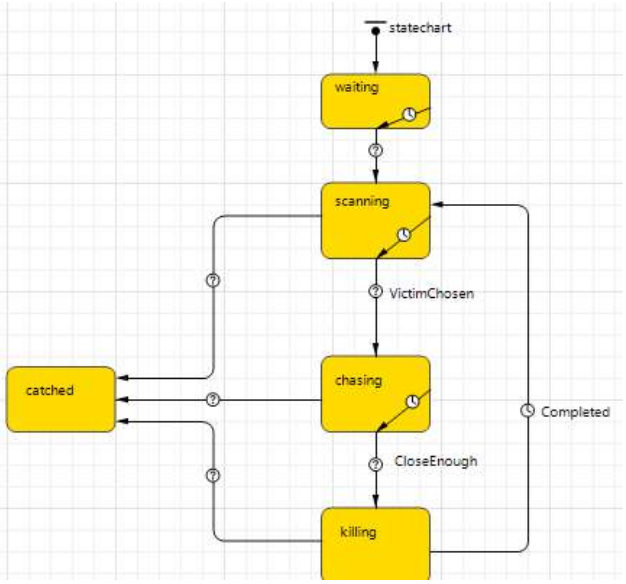

Figure 4. Perpetrator Status

As shown in Figure 5, the police officers are in three states: scan, find and fight. In the process modeling library, Select Output module makes conditional judgment on the behavior of the police officer and define the agent through the command! agent.inState (Security.fight). If the condition is true, the police officer will confront and arrest the perpetrator. The initial speed is set at 1m / s. The behavior state of the police is set through the state diagram, the behavior of restraining perpetrator is defined by the command sendToAll ("fight") .

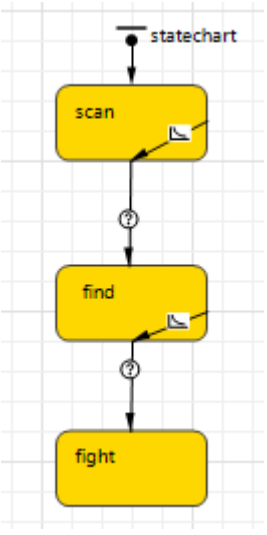

Figure 5. Police Status

4. Analysis of Experimental Results

The simulation experiment in this study is on the basis of the principle of social force model, using the pedestrian

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library module in AnyLogic platform. When the simulation starts, there are three security personnel on the first floor of the shopping mall by default, and the police officers on duty are transferred in the venue. In order to acquire the comparison results intuitively, the number of police officers is set to 1, 2 and 5 respectively as three different schemes.When the number of people inside the shopping mall is relatively stable, the researcher clicks the button of perpetrator to start the incident, and the crowd starts to escape, then the police and security personnel handle it. Each scheme is tested repeatedly for several times to obtain different data, and the number of police and the time required to arrest the perpetrator are analyzed.

The experimental results show that when there are three security personnel on the first floor of the shopping mall by default, additional police officers are deployed to patrol the venue, and the patrol route is always around the center of the shopping mall. When the emergent incident occurs, the nearby security personnel and the police on duty rush to the scene to deal with the perpetrator. When the number of police officers increases gradually, it is intuitive that the time needed to arrest the perpetrator will decrease accordingly. By conducting statistical analysis of the obtained data, the results are illustrated as follows:

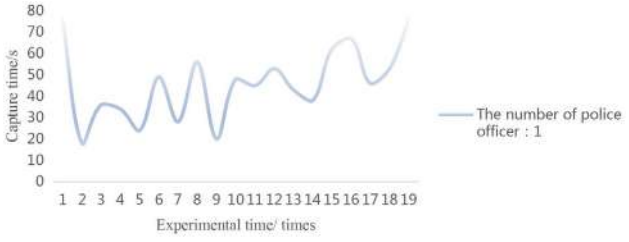

Figure 6. Statistics of capture time when the number of police officer is 1

It can be seen from Figure 6 that when a police officer is added to the shopping mall, the time taken to arrest the perpetrator is between 18s and 76s after the happening moment of incident,omitting the minimum value and the maximum value, the average restraining time is approximately 43.9s.

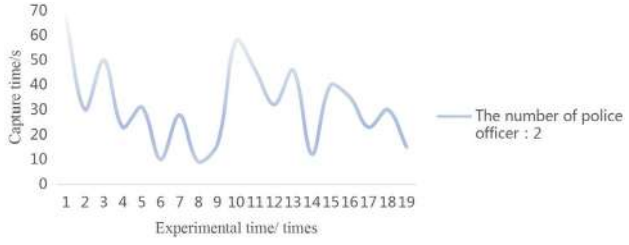

Figure 7. Statistics of arrest time when the number of police officers is 2

It can be seen from Figure 7 that when two police officers are added to the shopping mall for patrol, the time required to arrest the perpetrator is reduced after the happening moment of incident, and the time required is between 9s and 67s. The average calculation time is about 30.9s without the minimum value and the maximum value. Compared with the time when there is only one police officer, the time required to control the scene is reduced.

In order to make the results more intuitive and obvious, the number of police officers was set to 5 before the experiment, and the following results were obtained after repeated experiments:

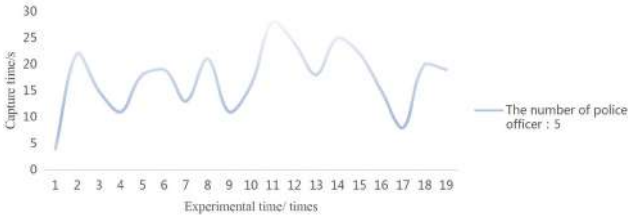

Figure 8. Statistics of arrest time when the number of police officers is 5

When the number of police on duty in the shopping mall is 5, the average time required to arrest perpetrator is merely 17.5 seconds omitting the maximum value and minimum value, and the time required to arrest perpetrator is much less than that of 1 or 2 involved police officer(s), which indicates that the increase of police officers can reduce the time taken to arrest the perpetrator.

In addition, the experimental results indicate that the use of AnyLogic platform can effectively simulate shopping mall emergencies and crowd interaction behavior, which can provide valuable reference for police force allocation and patrol route design.

5. Conclusion

This study utilizes AnyLogic platform to build a simulation model to simulate emergencies in shopping malls. The study collects the change of the time required to arrest the perpetrator under different numbers of police officers based on the experimental data from repeated experiments.The results proves the effectiveness of deploying certain police forces in large shopping malls for patrol under relatively ideal circumstances. In addition, it is also proved that AnyLogic can effectively simulate pedestrian interaction behavior and can be applied to the field of public security and police, so as to make great contribution to the data society and the intelligent policing.

As an exploratory study, there are still some deficiencies,

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such as the lack of experimental error analysis, and the limited exploration of whether the force value of police force and the perpetrator would affect the perpetrator restraining or not. In the future research, the above problems, including the experimental process as well as the parameter settings will be further refined and improved. In addition, the future research will attempt to introduce specific cases to further explore the crowd evacuation behavior in emergencies, and whether the police force or security personnel deployed in the shopping mall would affect the evacuation behavior of the crowd in the emergency or not.

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ARTICLE

Optimizing the Asset and Liability Management of Telecommunication Company using Goal Programming Model

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ABSTRACT

Since the telecommunications companies experience great competition, high churn rate, data traffic issues during the Covid-19 pandemic and the upgrade to 5G connectivity, the finance management of a telecommunications company should be analyzed to study the volatility and returns in the sector. This paper aims to develop a goal programming model to examine the asset and liability management of a telecommunication company, namely Telekom Malaysia Berhad (TM) in Malaysia. The result of this study shows that TM has achieved all the goals in maximizing assets, equities, profits, earnings and optimum management item while minimizing liabilities over the period of study from 2015 to 2019. Potential improvements on these goals have also been identified through this study. This paper has also contributed to the studies in financial management since past studies have not been done on asset and liability management in telecommunications companies which is rapidly growing and expanding even while the world is suffering from economy crisis during this pandemic.

1. Introduction

The current economy of the world is knowledge-based whereby productivity is enhanced by the sharing of timely and accurate information. This can be made achievable with telecommunication, which is defined as signal transmission and information exchange electronically [1]. Telecommunications industry, consisting of telecommunication infrastructure (fiber networks and telecommunication towers) and network operators (broadband, landline, cloud computing and data center) serves as a bridge that connects humans with humans and humans with machines. As at the end of 2019, the number of active internet users stood at more than 4 billion people across the world. More than 75% of these users are from developing countries [2]. Telecommunications have facilitated computer mediated communication to allow high accessibility to information database and interactions of different levels of employees across an organization. Telecommunication systems allow messages to be encoded, transmitted and decoded [3].

The government of Malaysia, through the Ministry of

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Communications and Multimedia has partnered up with various telecommunications companies in the country to launch and implement the Jalinan Digital Negara (Jendela) plan which aims to transform the country into a high-income digital society. This initiative aims to optimize current infrastructure for broadband, fiber and wireless connections to improve data traffic situations to prepare the country to welcome 5G connectivity in the near future [4]. It is also forecasted that the revenue brought by the telecommunication industry will exceed $9 billion by 2024 [5]. Being one of the selected telecommunication companies under the Jendela initiative, Telekom Malaysia Berhad (TM), is the longest existing telecommunication provider in Malaysia with a very extensive network coverage and offices in many major cities. Moreover, being a listed company under Bursa Malaysia, TM is known for its excellent corporate governance and ethical behaviors to its stakeholders which has positively impacted the company's performance [6].

Telecommunication industry has been experiencing high customer churn rate as the number of players has increased and the market has become highly saturated with the transition of traditional voice and text messages to data-based usages [7]. Even though TM has been dominant in the country, over the years, many new players such as Maxis Communications Berhad, Digi Telecommunications Berhad, Celcom Axiata Berhad and U Mobile Sdn Bhd have entered the industry and segmented the customer base [8]. Moreover, in the current Covid-19 pandemic, remote working has become a norm in the society. Many organizations are moving their working activities, meetings and conferences online which increases the need for telecommunication services. Teachers and students are engaging in online teaching and learning platforms for their daily classes; investors are performing financial transactions using online banking services; governments are sharing information on the number of cases, measures and efforts to contain the virus to the public through their official accounts on social media [9]. Network usage and voice calls soar which then bring down the quality of connection. Consumers, especially business owners and employees place great demand for smooth and unlimited connectivity while telecommunication companies usually offer services with bandwidth caps. As such, telecommunications companies are pressured to be flexible to offer more plans during this period. Such remote working plans have also caused the delay of 5G connectivity delivery which further hampers the future projects and revenue of telecommunications companies [10].

Since telecommunication sector is of tremendous importance, the financial health of a telecommunication company is important to help in future decision making in investments and other financial activities. Financial performance analysis and financial management can be done by interpreting data available in the balance sheet and income statement of the financial statements of a company [11]. Under financial management, the practice of asset and liability management (ALM) to manage a company to coordinate decision making by considering assets and liabilities is often used. The purpose of ALM is to mitigate risk, enhance liquidity and obtain high return from investments [12-13].

Since ALM involves multiple goals, goal programming (GP) model has been proposed to determine the optimal solution. GP is a popular type of multi-criteria decision making (MCDM) model. MCDM involves determining the best solution based on multiple criteria [14-23]. GP model overcomes the limitation of traditional linear programming models which could only solve a single goal. Guijarro and Poyatos [24] used GP model to overcome the limitations of arithmetic and geometric measurements to compute the composite sustainable development goal index. GP has been used for transportation and logistics planning [25,26], supplier selection [27] and location selection [28].

In financial management, multiple objectives have been adopted in developing the GP model, namely total assets, total liabilities, total equities, profits, earnings and optimum management items [29,30]. Based on previous studies, thorough research has not been carried out on the financial management of a telecommunication company using GP model. Therefore, this paper aims to develop a GP model to optimize the financial management for TM based on multiple goals such as total assets, total liabilities, total equities, profits, earnings and optimum management items. The next section of this paper shall be data and methodology, followed by empirical results and finally a conclusion.

2. Data and Methodology

GP model is an improvement from the linear programming model due to the limitation that linear programming is only able to optimize one objective with few linear constraints [31]. In the telecommunications industry, TM is having more than one objective besides maximizing profit in order to satisfy all the other stakeholders such as the administration, competitors, vendors, consumers, stockholders and the public. With resource scarcity problem, TM has to fulfill all these objectives to become more competitive. Therefore, this study shall investigate and optimize the financial management of TM which is

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listed in Bursa Malaysia from the year 2015 to 2019 using the GP model. The goals of the financial management of TM are presented in Table 1.

Table 1. Goals of Asset and Liability Management in TM

Goals	Objectives
1	Maximize total assets
2	Minimize total liabilities
3	Maximize total equities
4	Maximize profits
5	Maximize earnings
6	Maximize optimum management item

In a GP model, the goals shall be expressed as constraints whereby the coefficient of the variable will signify the level of importance of the goal. A higher coefficient value will reflect higher level of significance and vice versa. The GP model can be formulated as follows.

$$minz=w_1G_1+w_2G_2+\cdots+w_iG_i \quad (1)$$

in which i=1,2,3…,n,

subject to

$$\sum_{j=1}^{m}\left(a_{ij}x_j+d_i^--d_i^+\right)=g_i \quad (2)$$

$x_j,d_i^-,d_i^+\geq 0$

where

z = objective functions,

w_i = weightage for i=1,2,3…,n,

d_i^- = the underachievement for i=1,2,3…,n,

d_i^+ = the overachievement for i=1,2,3…,n,

x_j = decision variables for j=1,2,3…,m,

a_{ij} = parameters for decision variables,

g_i = benchmark for i=1,2,3…,n,

d_i^+ and d_i^- are the representations of overachievement and underachievement of the goals which add to the equations. When a goal is to be maximized, goal achievement happens when there is no underachievement value so that the modal value shall be equal to or more than the benchmark value. On the other hand, if a goal is to be minimized, goal achievement is reached when there is no overachievement so that the modal value shall be equal to or less than the benchmark value.

Financial data extracted from the financial statements of TM is represented in Table 2.

Table 2. Financial Data of TM

Goals	Group (RM'000,000)					Total
	2015	2016	2017	2018	**2019**	
Asset	24413	25002	24762	23705	25600	123481
Liability	16374	17169	16995	16689	19047	86274
Equity	8039	7833	7767	7016	6553	37207
Profit	592	613	731	17	557	2511
Earning	1231	1201	1101	376	1300	5208
Total	50649	51818	51355	47802	53057	254680

The coded configurations in developing constraints and equations in the GP model are shown in Table 3.

Table 3. Coded Configurations of the Financial Data of TM

Goals	Group (RM'000,000)					Total
	2015	2016	2017	2018	2019	
Asset	0.024413	0.025002	0.024762	0.023705	0.025600	0.123481
Liability	0.016374	0.017169	0.016995	0.016689	0.019047	0.086274
Equity	0.008039	0.007833	0.007767	0.007016	0.006553	0.037207
Profit	0.000592	0.000613	0.000731	0.000017	0.000557	0.002511
Earning	0.001231	0.001201	0.001101	0.000376	0.001300	0.005208
Total	0.050649	0.051818	0.051355	0.047802	0.053057	0.254680

From equation (2), x_j states the magnitude of each decision variable in each financial year.

Decision variable:

x_1=magnitude of each decision variable in the financial year 2015

x_2= magnitude of each decision variable in the financial year 2016

x_3= magnitude of each decision variable in the financial year 2017

x_4= magnitude of each decision variable in the financial year 2018

x_5= magnitude of each decision variable in the financial year 2019

Therefore, the formulation of the goal constraints in this GP model shall be as follows.

Assets:

$0.024413x_1+0.025002x_2+0.024762x_3+0.023705x_4+0.025600x_5\geq 0.123481$

Liabilities:

$0.016374x_1+0.017169x_2+0.016995x_3+0.016689x_4+0.019047x_5\leq 0.086274$

Equities:

$0.008039x_1+0.007833x_2+0.007767x_3+0.007016x_4+0.006553x_5\geq 0.037207$

Profits:

$0.000592x_1+0.000613x_2+0.000731x_3+0.000017x_4+0.00$

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$0557x_5 \geq 0.002511$

Earnings:

$0.001231x_1+0.001201x_2+0.001101x_3+0.000376x_4+0.001300x_5 \geq 0.005208$

Optimum management item (Total goal achievement):

$0.02649x_1+0.051818x_2+0.051355x_3+0.047802x_4+0.053057x_5 \geq 0.254680$

Assets, equities, profits, earnings and optimum management item shall be maximized while liabilities should be minimized in TM. The deviation variables, both positive and negative, which has to be minimized to indicate high goal achievement, will be included in every constraint to observe the trends of the goals. The GP model is then shown below.

The objective function:

$Minimize=d_1^- + d_2^+ + d_3^- + d_4^- + d_5^- + d_6^-$

Subject to:

$0.024413x_1+0.025002x_2+0.024762x_3+0.023705x_4+0.025600x_5+d_1^- - d_1^+ = 0.123481$

$0.016374x_1+0.017169x_2+0.016995x_3+0.016689x_4+0.019047x_5+d_2^- - d_2^+ = 0.086274$

$0.008039x_1+0.007833x_2+0.007767x_3+0.007016x_4+0.006553x_5+d_3^- - d_3^+ = 0.037207$

$0.000592x_1+0.000613x_2+0.000731x_3+0.000017x_4+0.000557x_5+d_4^- - d_4^+ = 0.002511$

$0.001231x_1+0.001201x_2+0.001101x_3+0.000376x_4+0.001300x_5+d_5^- - d_5^+ = 0.005208$

$0.02649x_1+0.051818x_2+0.051355x_3+0.047802x_4+0.053057x_5+d_6^- - d_6^+ = 0.254680$

$x_1, x_2, x_3, x_4, x_5, d_1^-, d_2^-, d_3^-, d_4^-, d_5^-, d_6^-, d_1^+, d_2^+, d_3^+, d_4^+, d_5^+, d_6^+ \geq 0$

In this study, the computational work is done using LINGO software. LINGO solves linear, non-linear, integer and goal programming model in optimization problem.

3. Empirical Results

The optimum solution of the goal achievement of TM using the GP model is shown in Table 4.

Table 4. TM's Model Value and Goal Achievement

Goal	Benchmark value	Model value	Negative deviation variable	Positive deviation variable	Goal achievement
Asset	0.123481	0.123482	0	0.000001	Achieved
Liability	0.086274	0.086274	0	0	Achieved
Equity	0.037207	0.037208	0	0.000001	Achieved
Profit	0.002511	0.002511	0	0	Achieved
Earning	0.005208	0.005208	0	0	Achieved
Optimum management item	0.254680	0.254680	0	0	Achieved

From Table 4, all the six goals, which are asset, liability, equity, profit, earning and optimum management item are achieved by TM in this study. This result is in line with the past study of Arewa et al. [29] which indicates that the goals or benchmark values are achieved by the company based on the optimal solution of GP model.

According to Table 4, for maximization goals, such as asset, equity, profit, earning and optimum management item, the negative deviation variables are zero which means that these model values are equal to or larger than the benchmark values. The positive deviation variable for minimizing total liability has also recorded a zero value, which means that there is no overachievement in terms of total liabilities. For total liabilities, the model value equals to the benchmark value.

In terms of total assets, TM managed to outperform by RM0.000001 trillion based on $d_1^+ = 0.000001$. Total liabilities will stay constant at RM0.086274 trillion since $d_2^-=0$. There is also potential improvement of RM0.000001 trillion for total equities because $d_3^+=0.00001$. Since all the positive deviation variables stated zero for profit, earning and optimum management item, they shall remain at RM0.002511 trillion, RM0.005208 trillion and RM0.254680 trillion respectively. The result of this study is supported by Halim et al. [32] which shows that the GP model provides insights on the potential improvement on the goals such as equity based on the optimal solution. Furthermore, the result of this study is in line with Halim et al. [32] which indicates that all the goals have been achieved based on the optimal solution of GP model.

4. Conclusion

This study develops a GP model to investigate and optimize the financial management of a telecommunication company, namely TM in Malaysia. Upon formulation and optimization, all the six goals, which are total asset, total liability, total equity, profit, earning and optimum management item, have been achieved. It can be deduced that TM is experiencing a healthy and stable financial performance from the year 2015 to 2019. There are also potential enhancements on these six goals which have been found based on their respective deviation from the benchmark value. As for continuous improvements, the deviations have also helped in setting new benchmark values for the goals. Future studies can focus on the financial management of telecommunications companies in other countries. Regression analysis may also be done to study the relationship of ALM with a firm's financial performance. Canonical correlation analysis may also be adopted to study the ALM strategies adopted by TM to maximize returns and manage risks.

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